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Volume 122(1)

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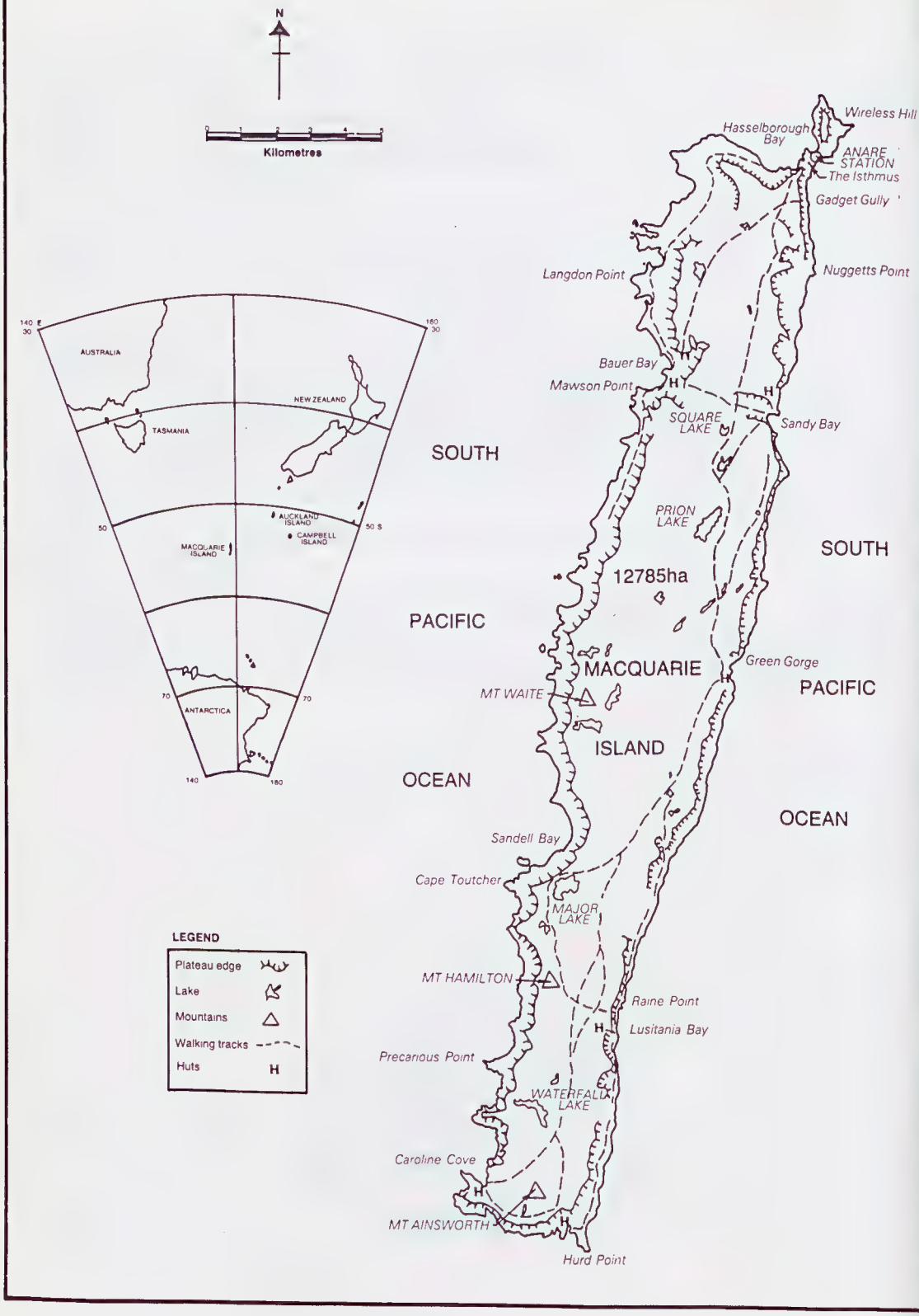
MACQUARIE ISLAND SYMPOSIUM
HOBART, MAY 1987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MACQUARIE ISLAND — A WONDER SPOT OF THE WORLD

by M.M. Bryden

BRYDEN, M.M., 1988 (viii): Macquarie Island — a wonder spot of the world. *Pap. Proc. R. Soc. Tasm.*, 122(1): 1–7. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Formerly University of Queensland, now Department of Veterinary Anatomy, University of Sydney, New South Wales, Australia 2006.

The geographical position, and geological and cultural history of Macquarie Island render it an important site for continued observations in upper atmosphere physics, meteorology, geology and many aspects of biology, especially those concerned with the Southern Ocean ecosystem and the control of introduced species. (Ed.)

Key Words: Macquarie Island, Southern Ocean, population studies, island flora and fauna, meteorology, aurora, mid-ocean ridge.

INTRODUCTION AND HISTORICAL COMMENTS

The title of this address reflects the sentiment of Sir Douglas Mawson, who, in a paper read to the South Australian branch of the Royal Geographical Society of Australasia in 1919, stated:

> "This little island is one of the wonder spots of the world. It is the great focus of the seal and bird life in the Australasian sub-Antarctic regions, and is consequently of far greater significance and importance in the economy of that great area than its small dimensions suggest."

This contrasts sharply with earlier statements (see Cumpston 1968, pp.60, 66) by Captain Douglass, master of the ship *Mariner* that visited Macquarie Island in 1822:

> "As to the island, it is the most wretched place of involuntary and slavish exilium that can possibly be conceived; nothing could warrant any civilized creature living on such a spot, were it not the certainty of industry being handsomely rewarded...",

and the *Hobart Town Gazette* of 4 February 1826, commenting on the advisability of establishing a penal settlement there:

> "The remote and stormy region in which Macquarie Island is placed, is a strong reason against the adoption of that sterile place as a penal settlement."

Macquarie Island, at latitude 54°30′S and longitude 158°57′E, lies just to the north of the Antarctic Convergence, 1466 km (833 nautical miles) southeast of Hobart, and 1294 km (735 nautical miles) from the antarctic continent. It is an exposed fragment of the crust of the Macquarie Ridge Complex which runs south from New Zealand, towards the Balleny Islands. The island is 34 km long and up to 5 km wide (120 km^2), its long axis running roughly northeast, and comprises a long narrow plateau, 250–350 m above sea level, bounded on all sides by steep slopes (20°–40°) or cliffs rising either directly from the coast or from a raised beach terrace.

Cumpston (1968) saw it as

> "standing like a signpost pointing the way to the frozen lands and seas of the antarctic region ... the last vestige of land to be found in the vast expanse of the Southern Ocean to the south of Australia."

Since the earliest days of visits and temporary occupation, Macquarie Island has been attached as a dependency to Tasmania. It is within the Municipality of Esperance. In 1890 an endeavour was made by the New Zealand Government to annex it, but this was unsuccessful (Mawson 1922). Subsequently, representations were made to transfer jurisdiction over the island to the Commonwealth Government, but that was never effected.

Early scientists to visit the island commented particularly on the abundance of wildlife, and its scientific interest. Prior to the Australasian Antarctic Expedition 1911–14, the only important contributions to the natural history of Macquarie Island were those of Scott (1883) and Hamilton (1895). Sir Douglas Mawson devoted the greater part of his paper "Macquarie Island and Its Future", read to the Royal Society of Tasmania (Mawson 1922), to a discussion of the animal life of the island. It is clear that he saw that as scientifically the most interesting aspect of Macquarie:

> "... the island is quadruply unique in the Australasian seas. Firstly, for the abundance of its life; secondly, for the variety of species frequenting its shores ...; thirdly, for the fact that it is the ... only possible breeding place for such life in those seas; finally, for the fortunate circumstance that up to the present man has not completely wrecked nature's handiwork, though certain spheres of life formerly abundant are now extinct, and others so greatly reduced that they are in danger of complete extermination."

This gives me some comfort in delivering the present address; although much has changed in the 65 years since Mawson's address, I perceive biology at Macquarie Island as being most important still. However, the fact that I accentuate biology in this address reflects my knowledge and special interests, and not necessarily the relative importance of the various scientific disciplines. I have had lengthy discussions with a number of people in other scientific areas, and their opinions and advice have been most valuable to me in composing this address.

One might expect that Mawson would have emphasised the geology of Macquarie Island more than he did, instead of its biological significance. However, it is as a result of concepts developed in recent years, especially the concepts of plate tectonics, that the great geological importance of Macquarie Island has been realised.

The Australian National Antarctic Research Expeditions personnel have maintained a scientific station on Macquarie Island continuously since 1948. Research projects have concentrated in the disciplines of biology, geology, upper atmosphere physics, cosmic ray physics, and meteorology, although other disciplines have been represented from time to time.

CONTRIBUTIONS OF RESEARCH AT MACQUARIE ISLAND

As I see it, the contributions to these different scientific disciplines of research at Macquarie Island fall into three major categories: (1) those involving collection of data at Macquarie Island, to be added to those gathered elsewhere, thereby providing a broader picture; (2) intrinsic studies, largely descriptive, that reflect the geological history and natural history of the island itself; (3) those that exploit the unique position or features of the island, and potentially provide new scientific insights.

Broad Picture

I place in this category the fields of seismology, cosmic ray physics, and certain aspects of geology, meteorology and biology. Because the island is so far from any other land mass, meteorological, seismological and cosmic ray information collected there provides a body of data in what would otherwise be a large void. This contribution is becoming less important in certain respects now, with access to advanced technology, but, nonetheless, local observations do provide detailed information not obtainable by other means.

For historical reasons, the island has presented an opportunity to examine several general questions in biology: for example, the extensive depletion and subsequent recovery of populations of animals (royal and king penguins), colonisation or recolonisation (fur seals), and the effects of introduced species (rats, mice, cats, rabbits, wekas) on the ecology of the island. Further, the results of control or eradication of introduced species on the fauna and flora of the island could provide valuable insights. Ecological investigations of animal populations at Macquarie Island and antarctic stations have provided further information on which to base ecological concepts (see Carrick 1964, Carrick & Ingham 1967).

Descriptive Studies

The structure and ecology of Macquarie Island have been examined from many points of view. There is a substantial body of knowledge relating to its climate, geology, lakes and streams, flora, fauna and littoral zone; some oceanographic investigations have been conducted in the region. (For a comprehensive list of publications, see Selkirk *et al.* 1986.) A very brief summary is presented here, much of the information having been drawn from Jenkin's excellent descriptions (Jenkin 1975).

The dominant influence on the climate of the island, associated with its location, is the surface temperature of the surrounding ocean. This, in turn, is influenced strongly by ocean currents. As a result of this and of the position of the island, to the north of the Antarctic Convergence, the climate is extremely oceanic with a uniform temperature regime. Precipitation occurs in some form on most days of the year (in excess of 300 days). This resultant excess of precipitation over evaporation and consistently high humidity result in a moist, drought-free environment.

The rocks of Macquarie Island form an almost unaltered ophiolite complex of mid-Tertiary age, upthrust in association with tectonic activity along the margin of the Indian–Australian plate. Evidence of apparent glacial activity exists, but there is debate about whether, in fact, the island was glaciated during the last glacial maximum. It has been suggested that supposedly glacial features can be explained in terms of structural control, by faulting and rapid uplift.

The soils in areas of maximum exposure, as on the plateaux, are mainly gravelly loams. Elsewhere acid peats predominate, differentiated into various types according to drainage. The organic matter generally masks the effects of different parent materials.

Drainage of water from the plateaux is either directly via streams, or into the numerous lakes, some of which in turn are drained by streams, others by subterranean seepage. Periods of heavy rain usually result in increased erosion of the steep coastal slopes. Although it has been assumed that grazing by rabbits has denuded the slopes, causing extensive erosion, there is recent evidence that rabbit activity has had minimal effect on overall rates of erosion, even though it appears significant in localised areas (Griffin 1980, Selkirk *et al.* 1983).

The chemistry of the island lake waters is influenced by the surrounding sea: salinity of lake waters depends on distance from the west coast, that is, in the direction of the prevailing westerly winds.

The flora comprises vascular species, mosses, liverworts and lichens. Broadly, grassland occurs on the coastal slopes, herbfield, fen and bog on the beach terraces and relatively flat, sheltered upland areas, and fellfield on the plateaux. With increasing altitude or exposure, the vegetation in all formations shows a progressive reduction in size and vigour.

Because the island always has been isolated from other land masses, the establishment of its non-marine flora must have been by long-distance transoceanic dispersal. Numerous exotic pollen and spore types occur in Holocene lake deposits.

The fauna of Macquarie Island has received considerable attention. There are many publications describing the species of invertebrates, including arthropods (more than 100 species), annelids, platyhelminths and a land mollusc on the island; littoral molluscs, echinoderms, brachiopods and chordates (ascidians); and marine bacteria and other micro-organisms, echinoderms, molluscs, nemerteans and arthropods (crustaceans). The vertebrates are spectacular, and large in numbers but not in variety. In the seas surrounding the island, several species of fishes and certain cetaceans have been identified. Macquarie Island is a breeding ground for very large populations of seabirds and seals. A few species of non-marine birds have been recorded. The vertebrate wildlife was exploited for more than a century from the time of discovery of the island in 1810, and this inevitably modified the original biota. The specific identity of the original fur seal, which was exterminated within a few years after 1810, is not known. An endemic rail and a parakeet became extinct, and rats, mice, wekas, cats, rabbits, a slug and a mite became established. Predation by cats probably has affected bird populations, particularly burrow-nesting species; burrowing and grazing by rabbits have modified vegetation to some extent and contribute locally to erosion.

Studies Exploiting the Unique Position or Features of the Island

Meteorology

The Australasian Antarctic Expedition in 1911–14 established the value of Macquarie Island as a meteorological station. F.M.B. Fisher, Minister in Charge of the Meteorological Department in New Zealand in 1913, stated, among other things, that he attached great importance and much value to the daily messages from Macquarie Island. A committee of the Australasian Association for the Advancement of Science stressed the importance of maintaining the wireless station at Macquarie Island in that

> "(1) in the matter of meteorological forecasts and warnings to shipping, the station has already proved its value, (2) important general results are to be obtained by the scientific study of the weather conditions of the far south, as those conditions are related to those in the temperate regions." (For sources see Cumpston 1968.)

These points are still valid as I understand it. When the antarctic station of Mawson was established, it was necessary to close one of the other stations. A major reason for retaining the station at Macquarie Island rather than Heard Island was that the former is more valuable as a meteorological station in relation to Australasian meteorological studies: Heard Island contributes only indirectly.

Overall, the benefits of Macquarie Island as a weather station for short-term forecasting in southern Australia and New Zealand have diminished in importance as improved records from

satellites have become available. However, at the same time the importance of Macquarie Island as a ground-truthing station has increased. It is a most valuable platform from which to monitor long-term changes or trends in the climatic record.

Upper Atmosphere Physics

Camps were established at the isthmus and Hurd Point, near the northern and southern ends of the island respectively, during the International Geophysical Year, 1956. Simultaneous observations enabled accurate estimates to be made of the distance of the aurora, obtained by triangulation, a measurement that is surprisingly difficult to obtain.

Macquarie Island lies towards the equator from the southern auroral zone, forming a conjugate pair with Kotzebue in Alaska. It has been suggested that this conjugate pair is well positioned to investigate the characteristics of auroral substorms on the global scale. These regions are particularly suitable for conjugate investigations, because they lie within the closed magnetic field line region; in addition, post-breakup pulsating auroras, associated with strong absorption increases, occur most frequently equator-wards of the auroral zone (Hajkowicz 1969).

Investigations of the visible aurora are made difficult at Macquarie Island because of the prevalence of cloud cover. The interrelationship of the auroral phenomenon and other events in the upper atmosphere at Macquarie Island are somewhat similar to that in parts of New Zealand and southern Australia.

Geology

The Macquarie Ridge runs south from New Zealand, Macquarie Island itself being an exposed portion of the ridge. The entire ridge formed as a result of interactions along the congruent margins of the Indian-Australian and Pacific plates. The island is a rare example of uplifted oceanic crust, detailed examination of which provides insight into how the oceanic crust was formed. Such insight is difficult, if not impossible, to obtain from studies of the ocean floor itself. Macquarie Island is, therefore, a critical area for the study of the oceanic crust and ocean tectonics.

Zoology

Macquarie Island has been recognised as being important zoologically for a long time, as we have seen already. Because of its position, the only speck of land in the vast expanse of ocean to the south of Australia and New Zealand between latitude 52°S and the Antarctic Circle, it is an important place to examine critical aspects of the ecosystem of the Southern Ocean.

Some descriptions and species lists resulted from the activities of members of the Australasian Antarctic Expedition 1911–14 and the British, Australian and New Zealand Research Expedition 1919–31, and in the early days of the Australian National Antarctic Research Expeditions (see references in Selkirk *et al.* 1986). A major upturn in biological research at Macquarie Island occurred in the 1950's and 1960's, when long-term investigations of elephant seals and royal penguins, supervised by Dr R. Carrick of the CSIRO Division of Wildlife Research, were undertaken. A series of papers by Carrick and others was published in *CSIRO Wildlife Research*, volume 7, in 1962. As an adjunct to those projects several more restricted but related investigations involving anatomy, physiology and ethology of seals and penguins were undertaken (see Bryden 1964 *et seq.*, Ling 1965 *et seq.*, Shaughnessy 1970a, 1974, 1975, Smith 1974), and studies of certain other species, particularly birds, were made (see for example Mackenzie 1968, Purchase 1980, Shaughnessy 1970b, c, 1971, Simpson 1965a, b).

In the 1970's the emphasis of zoology, by then supervised within the Antarctic Division, shifted to the antarctic continent, where extensive studies were centred at Davis. The major thrust was in limnology at that time. Monitoring of populations continued at Macquarie Island, and an intensive investigation of the control of the annual cycle of elephant seals was conducted (see Griffiths *et al.* 1979, Griffiths & Bryden 1981, Griffiths 1984 *et seq.*). At the end of that decade the emphasis shifted again, when marine biological investigations began. This was an important development and was seen as a valuable contribution by Australia to the BIOMASS Programme (Biological Investigations of Marine Antarctic Systems and Stocks).

In the last three or four years the importance of Macquarie Island zoologically, mainly as a result of its location, has been re-emphasised. The knowledge now that certain animal populations are undergoing dynamic change in the Southern Ocean has pointed up the need for major zoological studies at Macquarie Island to supplement the marine biology programmes. There is solid evidence that the elephant seal population at Macquarie Island has declined by 50% in the last 30-odd years (Hindell & Burton 1987), and some preliminary investigations of factors associated with that decline have been undertaken (Little *et al.* 1987).

Throughout the 1970's and early 1980's other aspects of biology continued. These included

- making collections of biota for selected studies of flora and fauna, in particular algae and aquatic invertebrates;
- continuation of long-term population studies of seabirds, particularly the wandering albatross, the light-mantled sooty albatross and the giant petrels; more recently, the black-browed albatross and the grey-headed albatross have been included;
- control programmes: initial surveys and experimental control of rabbits and cats were conducted as early as the 1960's, and control procedures have been employed since then; control of rodents and wekas has been attempted more recently;
- monitoring seabirds: this represented an involvement in an International Survey of Antarctic Seabirds; photographic censuses of all the major penguin colonies on the island were carried out;
- making a census of fur seals: general study of the fur seals at Macquarie Island was conducted as early as the 1950's (Csordas & Ingham 1965); recently it has been recognised that there are three species of fur seal at the island, the New Zealand fur seal which is a visitor only, the antarctic fur seal and the subantarctic fur seal;
- recording and tagging leopard seals;
- studies of diet of the four species of penguin, gentoo, royal, king and rockhopper.

The Commission for the Conservation of Antarctic Marine Living Resources, now established in Hobart, has recognised for several years that high-level consumers, such as seals, penguins and other seabirds, may be valuable "biological indicators" of the condition of the Southern Ocean ecosystem. The long-term censuses and population studies that have been conducted over several years will continue to be most valuable in this regard.

THE FUTURE

There is little doubt that Macquarie Island continues to be an important meteorological station and presents opportunities to conduct unique investigations of the aurora and other aspects of the upper atmosphere. Exciting geological work is currently being conducted at the island. All these aspects will be addressed elsewhere in this volume.

The recognition by Mawson and some before him that the fauna of Macquarie Island is of principal importance is as true today as it was early this century. However, our perception of what constitutes its importance could hardly be more different from that of Mawson. In this regard it is interesting to reflect on the future management of the fauna of Macquarie Island put forward by Mawson (1919):

(1) ensure that only redundant bull elephant seals and decrepit animals are killed;
(2) kill any sea leopards that come ashore;
(3) reduce the number of skua gulls;
(4) investigate the possibility of a penguin egg industry;
(5) reduce, and if possible exterminate, the wild cats;
(6) breed a few sheep in a restricted area on North Head;
(7) introduce the fur seal and possibly other fur-bearing animals.

The potential value of seals and seabirds as biological indicators of the status of the ecosystem of the Southern Ocean has been mentioned above; censuses of these species should continue, in particular the penguins and elephant seals. Detailed ecological investigations of these species may shed valuable light on the factors responsible for fluctuations in population size. Technology is being developed, and in some cases is available now, to examine their range, short-term and long-term movements, energetics, diving and foraging behaviour. It will be possible to compare these factors among age and sex classes.

The fur seals at Macquarie Island present an excellent opportunity to examine ecology and behaviour in an apparently developing population that may be unique. The interrelationships among New Zealand, antarctic and subantarctic fur seals, and possible interbreeding between subantarctic and antarctic species, potentially are a fertile field for ecological study.

Hitherto, physiological investigations of the fauna at Macquarie Island have been few. The opportunity for such studies provided by the island fauna is not unique on a world scale, but it does present the only practicable opportunity for such work by Australians in Australia. Recent investigations have been aimed at examining the role of the pineal gland in southern seals (Griffiths & Bryden 1981, Bryden *et al.* 1986, Griffiths *et al.* 1986), and mechanisms of body temperature control in newborn seals (Little & Bryden, work in progress). It appears that changes in day length, which are marked in polar regions, are monitored by a mechanism involving the pineal gland, and are particularly important in controlling at least some annual cycles in the southern seals. It is likely that light, upon which most phytoplankton are dependent, has a significant influence on the marine

fauna of the Southern Ocean at many trophic levels. The physiology of energy transfer within species is potentially extremely important to our understanding of the mechanisms of shifts in the Southern Ocean system.

CONCLUDING REMARKS

In summary, Macquarie Island is as fascinating today as it was 70 and more years ago when scientists first visited it. The animal life is of particular interest, as it was when Sir Douglas Mawson visited the island earlier this century; the strategic importance of the island in the Southern Ocean has a different and even greater significance in this regard than was foreseen earlier. The declaration of the island as a fauna and flora reserve and, more recently, placing it under the control of the National Parks and Wildlife Service, Tasmania, have been vital. The introduction of measures to control feral species and ensure the continued well-being of natural populations have contributed significantly to improving the value of the island's populations of animals as monitors of the Southern Ocean ecosystem.

As a result of investigations in a number of scientific disciplines, we have an appreciation of the geological history of the island and its flora and fauna.

Macquarie Island continues to be an important meteorological station. Largely as a result of its geographic position, useful data in a number of scientific spheres continue to be recorded there.

In the 1980's we are reaping the benefits of wise planning and execution of scientific programmes at Macquarie Island by the Australian National Antarctic Research Expeditions over the past 39 years.

REFERENCES

BRYDEN, M.M., 1964: Insulating capacity of the subcutaneous fat of the southern elephant seal. *Nature*, 203: 1299–1300.

BRYDEN, M.M., GRIFFITHS, D.J., KENNAWAY, D.J. & LEDINGHAM, J., 1986: The pineal gland is very large and active in newborn antarctic seals. *Experientia*, 42: 564–566.

CARRICK, R., 1964: Southern seals as subjects for ecological research. *In* Carrick, R., Holdgate, M.W. & Prevost, J. (Eds): *BIOLOGIE ANTARCTIQUE. PREMIER SYMPOSIUM ORGANISE PAR LE S.C.A.R. PARIS 1962.* Herman, Paris: 421–432.

CARRICK, R. & INGHAM, S.E., 1967: Antarctic sea-birds as subjects for ecological research. *JARE SCIENTIFIC REPORTS. SPECIAL ISSUE NO.1. PROCEEDINGS OF THE SYMPOSIUM ON PACIFIC-ANTARCTIC SCIENCES, TOKYO*: 151–184.

CSORDAS, S.E. & INGHAM, S.C., 1965: The New Zealand fur seal, *Arctocephalus forsteri* (Lesson), at Macquarie Island, 1949–1964. *C.S.I.R.O. Wildl. Res.*, 10: 83–99.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1), Narrative. Publication no.93. Antarctic Division, Department of External Affairs, Australia.

GRIFFIN, B.J., 1980: Erosion and rabbits on Macquarie Island: some comments. *Pap. Proc. R. Soc. Tasm.*, 114: 81–83.

GRIFFITHS, D.J., 1984: The annual cycle of the epididymis of the elephant seal (*Mirounga leonina*) at Macquarie Island. *J. Zool. (Lond.)*, 203: 181–191.

GRIFFITHS, D.J. & BRYDEN, M.M., 1981: The annual cycle of the pineal gland of the elephant seal (*Mirounga leonina*). *In* Matthews, C.D. & Seamark, R.J. (Eds): *PINEAL FUNCTION.* Elsevier/North Holland, Amsterdam: 57–66.

GRIFFITHS, D.J., BRYDEN, M.M. & KENNAWAY, D.J., 1986: A fluctuation in plasma melatonin level in the Weddell seal during constant natural light. *J. Pineal. Res.*, 3: 127–134.

GRIFFITHS, D.J., SEAMARK, R.F. & BRYDEN, M.M., 1979: Summer and winter cycles in plasma melatonin levels in the elephant seal (*Mirounga leonina*). *Aust. J. Biol. Sci.*, 32: 581–586.

HAJKOWICZ, L.A., 1969: The role of post-breakup pulsating aurora in conjugate point absorption increases. *J. Atmos. Terr. Phys.*, 31: 1365–1370.

HAMILTON, A., 1895: Notes on a visit to Macquarie Island. *Trans. Proc. N.Z. Inst. 1894*, 27: 559–579.

HINDELL, M.A. & BURTON, H.R., 1987: Past and present status of the southern elephant seal (*Mirounga leonina* Linn.) at Macquarie Island. *J. Zool. (Lond.)*: in press.

JENKIN, J.F., 1975: Macquarie Island, Subantarctica. *In* Rosswall, T. & Heal, O.W. (Eds): *STRUCTURE AND FUNCTION OF TUNDRA ECOSYSTEMS.* Ecological Bulletins, Stockholm, 20.

LING, J.K., 1965: Functional significance of sweat glands and sebaceous glands in seals. *Nature*, 208: 560–562.

LITTLE, G.J., BRYDEN, M.M. & BARNES, A., 1987: Growth from birth to 20 days of the elephant seal (*Mirounga leonina*) at Macquarie Island. *Aust. J. Zool.*, 35: in press.

MACKENZIE, D., 1968: The birds and seals of the Bishop and Clerk Islets, Macquarie Island. *Emu*, 67: 241–245.

MAWSON, D., 1919: Macquarie Island. A sanctuary for Australasian subantarctic fauna. *Proc. R. Geogr. Soc. Aust., South. Aust. Branch 1918–1919*: 71–85.

MAWSON, D., 1922: Macquarie Island and its future. *Pap. Proc. R. Soc. Tasm. 1922:* 40–54.

PURCHASE, D., 1980: Giant petrel records from Fiji. *Notornis*, 27: 406–506.

SCOTT, J.H., 1883: Macquarie Island. *Trans. Proc. N.Z. Inst. 1882*, 15: 484–493.

SELKIRK, P.M., COSTIN, A.B., SEPPELT, R.D. & SCOTT, J.J., 1983: Rabbits, vegetation and erosion of Macquarie island. *Proc. Linn. Soc. N.S.W.*, 106: 337–346.

SELKIRK, D.R., SELKIRK, P.M. & SEPPELT, R.D., 1986: An annotated bibliography of Macquarie Island. *ANARE Res. Notes*, 38.

SHAUGHNESSY, P.D., 1970a: Ontogeny of haemoglobin in the Royal penguin *Eudyptes chrysolophus schlegeli*. *J. Embryol. Exp. Morph.*, 24: 425–428.

SHAUGHNESSY, P.D., 1970b: Genetics of plumage phase dimorphism of the southern giant petrel *Macronectes giganteus*. Heredity, 25: 501–506.

SHAUGHNESSY, P.D., 1970c: Serum proteins of two sibling species of giant petrel (*Macronetes* spp.). *Comp. Biochem. Physiol.*, 33: 721–723.

SHAUGHNESSY, P.D., 1971: Frequency of the white phase of the southern giant petrel *Macronetes giganteus* (Gmelin). *Aust. J. Zool.*, 19: 77–83.

SHAUGHNESSY, P.D., 1974: An electrophoretic study of blood and milk proteins of the southern elephant seal, *Mirounga leonina*. *J. Mammal.*, 55: 796–808.

SHAUGHNESSY, P.D., 1975: Variation in facial colour of the royal penguin. *Emu*, 75: 147–152.

SIMPSON, K.G., 1965a: The dispersal of regurgitated pumice gizzard-stones by the southern skua at Macquarie Island. *Emu*, 65: 119–124.

SIMPSON, K.G., 1965b: First record of a grey plover at Macquarie Island. *Emu*, 65: 77–78.

SMITH, G.T., 1974: An analysis of the function of some displays of the royal penguin. *Emu*, 74: 27–34.

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HERITAGE CONSERVATION IN ANTARCTIC AND SUBANTARCTIC JURISDICTIONS: THE CASE OF MACQUARIE ISLAND

by Bruce W. Davis

DAVIS, B.W., 1988 (viii): Heritage conservation in antarctic and subantarctic jurisdictions: the case of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 9–14. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Formerly University of Tasmania, now Public Policy and Administration, School of Social Inquiry, Murdoch University, Perth, W.A., Australia 6150.

Macquarie Island, in the subantarctic, is in a position of great importance for programmes of scientific research and nature conservation, but its historic value in the area of heritage conservation should also be recognised. A management plan should be formulated for protection of the features of the island in all these aspects.
Key Words: Macquarie Island, conservation, Antarctic Treaty.

INTRODUCTION

Most Australians know little of Macquarie Island but, if they have any vision of the place, probably assume it to be part of Antarctica, teeming with wildlife. In this symposium it is important not only to place on record current knowledge about Macquarie Island, but also to explain its contextual relationship to international programmes of scientific investigation and nature conservation. It is equally essential to recognise that Antarctica and the Southern Oceans are becoming a focus of international rivalries and concern; thus subantarctic dependencies such as Macquarie Island take on a new strategic significance. This paper is intended to set the scene for more detailed expositions of characteristics of the island, but the *political* implications of its existence as part of Australia must also be recognised.

TERRAIN AND WILDLIFE

Other commentators will explain in their papers details of the island's topography, climate, vegetation and wildlife, but here some basic facts are outlined.

Macquarie Island was discovered in 1810 by Frederick Hasselborough in the Sydney sailing brig *Perseverance* (Cumpston 1968). The island is located at latitude 54°37'S and longitude 158°54'E, in the Southern Ocean, approximately 1500 km southeast of Tasmania. When Van Diemen's Land was proclaimed in 1825, Macquarie Island was included in its charter and has subsequently been considered a subantarctic dependency of Esperance municipality, Tasmania.

The island is approximately 12 343 hectares in extent, some 34 km long (north–south) and up to 5 km wide, with a rocky shoreline backed by steep hills and cliffs, which form an undulating plateau 200–300 m a.s.l., with a maximum altitude of 433 m at Mt Hamilton. There are several adjacent sea-stacks and offshore islets. Macquarie Island is of volcanic origin, a horst block subsequently eroded by glacial action and possessing several lakes, but with no permanent ice. The island has a cold temperate climate with strong westerly winds, heavy cloud and a rainfall of approximately 900 mm per year.

There are no trees, but the island is extensively vegetated with tussock grasslands, herbs and sedges, and areas of peatbog. Numerous varieties of birds, penguins, elephant seals and fur seals abound; indeed, Macquarie Island is one of the great wildlife preserves of the world. Unfortunately, there are also some feral species, such as mice, rats, cats and rabbits; a mere remnant of diverse species introduced by man at various stages since 1810. Early interest in the island was entirely commercial, based on exploitation of penguin and seal resources for fur and oil. Macquarie Island was declared a sanctuary in 1933 and the only human habitation now extant is an Australian National Antarctic Research Expedition (ANARE) base in the north of the island, intended for meteorological and scientific use.

PROTECTION

Scientists began visiting Macquarie Island from 1833 onwards, and during the 1911–14 Australasian Antarctic Expedition (AAE), Sir Douglas Mawson established the first major scientific research station on the island. The efforts of various scientists, but principally Mawson, brought commercial exploitation of wildlife to a close by 1919 and in 1933 the Tasmanian Government declared the island to be a Wildlife Sanctuary

under the *Animals and Birds Protection Act* 1928. It was subsequently gazetted a State Reserve under the *Tasmanian National Parks and Wildlife Act* 1970, which came into effect in 1971–72, and in 1978 overall protection was upgraded to that of a Nature Reserve. All wildlife and natural features are now conserved and entry to the reserve is by permit. Alteration of regulations or any attempt at revocation of part of the reserve would require the assent of both Houses of the Tasmanian Parliament, so security of protection is high (TNPWS Report 1980). A detailed management plan is currently in preparation.

BIOSPHERE RESERVE STATUS

Macquarie Island is one of the twelve biosphere reserves within Australian jurisdiction, having been granted this status by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) in October 1977, as part of its Man and Biosphere (MAB) programme (Rounsevell & Copson 1985). Biosphere reserves are areas which, because of their characteristic plants and animals, and the way they are used by people, provide scientific reference points to compare human impacts on the environment with the effects of natural forces. A biosphere reserve therefore contains both relatively pristine areas and zones which have been modified by human activity, scientific monitoring being used to assess the differences. There is usually a protected core of relatively undisturbed terrain and one or more "buffer zones" in which experimental work is carried out (Davis & Drake 1983).

How are biosphere reserves different from other protected areas? The International Union for the Conservation of Nature (IUCN) recognises ten different types of protected areas, each with particular characteristics (IUCN 1978):

Category I	Scientific reserve/strict nature reserve
Category II	National Park
Category III	Natural monument/national landmark
Category IV	Nature conservation reserve/wildlife sanctuary
Category V	Protected landscape
Category VI	Resource reserve
Category VII	Natural biotic area/anthropological reserves
Category VIII	Multiple-use management area
Category IX	Biosphere reserve
Category X	World Heritage site (natural).

It is fairly obvious that Macquarie Island could qualify for any or all of Categories I, II, IV or IX status, but overall the reserve possesses qualities mainly evident in Categories I and IX, being a strict nature reserve, with limited areas assigned for scientific monitoring and investigation.

Australia's system of biosphere reserves has an important international value in setting reference points for assessing air quality, pollution and radioactivity levels, meteorological effects, the impact of introduced species and environmental damage caused by human activities. There are, however, many deficiencies and omissions in Australian monitoring programmes (Davis 1986a), and it cannot be argued that a systematic and thematic investigation plan exists for Macquarie Island as yet. A recent report on the conservation of subantarctic islands, prepared by an IUCN/SCAR (Scientific Committee on Antarctic Research) workshop (SCAR/IUCN 1986) does provide guidelines which should be followed in the future. Details of the principal recommendations are given as Appendix A of this paper.

ANTARCTIC TREATY PROVISIONS

The Antarctic Convergence lies some 200–250 km south of Macquarie Island; thus the nature reserve does not form part of Antarctica or automatically come under provisions of the Antarctic Treaty of 1959. In practice, however, there is a sensible and necessary connection. Many of the scientific programmes carried out on Macquarie Island are operated by personnel with antarctic interests, projects and experience; moreover, the data collected link in the comparative material from other subantarctic dependencies and the Antarctic Continent itself (Antarctic Division 1987). This is not to suggest that *all* research has antarctic implications, but the nexus is considerable and strengthening.

The three principles upon which the Antarctic Treaty is based, namely demilitarisation, international scientific co-operation and environmental protection, are as pertinent to Macquarie Island as to the frozen continent further south. These precepts are further reinforced by Australian statutes regulating research in Antarctica and subantarctic islands such as Heard, McDonald (Keage 1981) and Macquarie. The relevant legislation is as follows:

– the *Wildlife Protection (Restriction of Exports and Imports) Act* 1982;

- the *Whale Protection Act* 1980;
- the *Environmental Protection (Impact of Proposals) Act* 1974;
- the *Quarantine Act* 1908.

In addition, two statutes exist which give effect to agreements under the Antarctic Treaty system:

- the *Antarctic Treaty (Environment Protection) Act* 1980;
- the *Antarctic Marine Living Resources Conservation Act* 1981.

As we shall discover later, some aspects of the *Australian Heritage Commission Act* 1975 are also relevant.

CAMLR

The Convention on the Conservation of Antarctic Marine Living Resources (CAMLR) was signed in Canberra on 21 May 1980 and came into force on 7 April 1982. The fifteen original contracting parties included all thirteen full members of the Antarctic Treaty, together with the Federal Republic of Germany and the German Democratic Republic. The convention is widely acknowledged by member states to be part of the Antarctic Treaty system and operates south of 60° latitude and the Antarctic Convergence. Its primary aim is to secure international co-operation in marine research and ensure the conservation of particular fish species and the ecosystems upon which they depend (Commission CAMLR 1984). In recent times the Australian Government has expressed concern about slow implementation of the Convention, particularly ecosystems management; nonetheless, some achievements have been recorded and more are in prospect (Commonwealth of Australia 1985).

In theory, CAMLR does not apply to the waters surrounding Macquarie Island, but in practice there is a linkage through marine research programmes in the Southern Ocean. Australia is permitted to declare a 200-mile *economic zone* around Macquarie Island, under the provisions of UNCLOS III (the Law of the Sea), but has not yet done so. However, a 200-mile *fishing zone* does apply, although it is difficult to envisage how this could be effectively monitored or enforced. In brief, our knowledge of marine resources adjacent to Macquarie Island is scant and needs to be improved in the future.

HERITAGE CONSERVATION

Thus far, the paper has focussed on aspects of nature conservation and scientific research on Macquarie Island, but this neglects another important dimension, namely *heritage conservation*. Here we are concerned with aspects such as historic shipwrecks, industrial archaeology and the built environment, as much as natural features. The Australian Heritage Commission, a federal statutory authority established in 1975, has jurisdiction in this field. The Commission is responsible for advising the Federal Government about policy relating to conservation of the natural, built and cultural environment, and also compiles an inventory of significant places, known as the Register of the National Estate. The latter is defined (Australian Heritage Commission 1985) as "... those places being components of the natural environment of Australia or the cultural environment that have aesthetic, historic, scientific or social significance or other special value for future generations as well as the present community".

Except in special circumstances, listing of a place only highlights its significance and does not preclude any private owner, state or local government from exercising judgement about use of the place; however, the Act does bind the Commonwealth in a number of ways.

Section 30 of the *Australian Heritage Commission Act* 1975 requires all Federal Ministers to conserve National Estate values. Thus, if a Commonwealth action will impact upon listed places, ministers must examine the situation, consult the Commission and take all prudent and feasible measures which will conserve the essential heritage characteristics of the area. Since Macquarie Island is listed on the Register of the National Estate, Federal agencies and employees are enjoined to minimise human impacts upon biota, natural features, marine or industrial relics or historic buildings. The work of documenting and listing specific sites and artefacts on Macquarie Island is far from complete, but was described in other contributions to this symposium.

STRATEGIC IMPLICATIONS

It is tempting to assume that Macquarie Island will remain a windswept, hostile but fascinating wildlife refuge, with little human occupation or impact, but the island must be viewed against the broader spectrum of international rivalries and global politics. Although Antarctica is frequently depicted as a zone of peace, there *are* rival territorial

claims and underlying political tensions; more nations are becoming interested in the region and wish to have some say in its management (Beck 1986, Hall 1986). The question is whether the Treaty is robust or flexible enough to meet new demands in the years ahead. Similarly, the CAMLR convention is under test and the Law of the Sea has induced some developing nations to seek a share in the spoils, through "common heritage" arguments (Davis 1986b). In brief, we must be cognisant with the reality that Macquarie Island could have an importance beyond its natural beauty; that in formulating management plans for the island, state, national and international factors must be considered and the political implications of actions carefully weighed.

The stark grandeur of Macquarie Island, once witnessed, is not easily forgotten. May it continue to be haven of peaceful scientific research, aesthetic inspiration and wildlife conservation.

REFERENCES

ANTARCTIC DIVISION, 1987: *APPROVED ANARE SCIENCE PROGRAMME 1986–87.* Department of Science, Canberra.

AUSTRALIAN HERITAGE COMMISSION, 1985: *AUSTRALIA'S NATIONAL ESTATE: THE ROLE OF THE COMMONWEALTH.* Australian Government Publishing Service, Canberra.

BECK, P.J., 1986: Challenges to the Antarctic Treaty regime: The external political challenge. *In* Millar, T.B. (Ed.): *AUSTRALIA, BRITAIN AND ANTARCTICA.* Australian Studies Centre, Institute of Commonwealth Studies, University of London: 60–79.

COMMISSION CAMLR, 1984: *BASIC DOCUMENTS OF THE CAMLR CONVENTION.* CAMLR Secretariat, Hobart.

COMMONWEALTH OF AUSTRALIA, 1983: *THE ANTARCTIC TREATY SYSTEM.* Australian Government Publishing Service, Canberra.

COMMONWEALTH OF AUSTRALIA, SENATE STANDING COMMITTEE ON NATURAL RESOURCES, 1985: *THE NATURAL RESOURCES OF THE AUSTRALIAN ANTARCTIC TERRITORY.* AGPS, Canberra.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1). Antarctic Division, Department of External Affairs, Melbourne.

DAVIS, B.W., 1986a: The contribution of the social sciences to Australian antarctic research. *ASAC FORUM, PAPERS AND SUBMISSIONS*, Vol.2. Department of Science, Canberra, October 1986.

DAVIS, B.W., 1986b: Antarctica: Background to the present situation. *In* Millar, T.B. (Ed.): *AUSTRALIA, BRITAIN AND ANTARCTICA.* Australian Studies Centre, Institute of Commonwealth Studies, University of London: 4–18.

DAVIS, B.W. & DRAKE, G.A., 1983: *AUSTRALIA'S BIOSPHERE RESERVES: CONSERVING ECOLOGICAL DIVERSITY.* Australian National Commission for UNESCO, Australian Government Publishing Service, Canberra.

HALL, R., 1986: Antarctica in World Politics. Unpublished M.A. thesis, University of Tasmania.

IUCN, 1978: *CATEGORIES, OBJECTIVES AND CRITERIA FOR PROTECTED AREAS.* Morges, Switzerland.

JOHNSTONE, G.W., 1985: Threats to birds on subantarctic islands. *ICPB (International Council for Bird Preservation) Tech. Bull.*, No.3.

KEAGE, P.L., 1981: *THE CONSERVATION STATUS OF HEARD ISLAND AND THE McDONALD ISLANDS.* Environmental Studies, Occasional Paper 13. Centre for Environmental Studies, University of Tasmania.

ROUNSEVELL, D. & COPSON, G., 1985: Southern ocean sanctuary. *UNESCO Review*, No.10, March 1985, Canberra.

SCAR/IUCN, 1986: The biological basis for conservation of subantarctic islands. *REPORT OF A JOINT SCAR/IUCN WORKSHOP, PAIMPONT, FRANCE, SEPTEMBER 1986.*

TASMANIAN NATIONAL PARKS AND WILDLIFE SERVICE, 1980: *MACQUARIE ISLAND NATURE RESERVE.* Hobart.

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APPENDIX A
CONSERVATION MEASURES FOR SUBANTARCTIC ISLANDS IUCN/ SCAR RECOMMENDATIONS, 1986

Recommendations

The workshop made the following unanimous recommendations:

1. *Recommend*
that the severity of the impact of introduced plants and animals on these sensitive island ecosystems be urgently assessed, that appropriate control measures be instituted as soon as possible to minimise damage and that the ecosystems be monitored to assess recovery;

Encourage
national authorities to conserve, under strictly controlled conditions, a sample of those introduced species whose genetic resources are regarded as potentially useful, if this does not conflict with the conservation of endangered indigenous species.

2. *Recommend*
that all islands be protected from any new accidental introductions by Man and that all necessary inspection and quarantine procedures to ensure this be brought into use as soon as possible;

Encourage
national authorities to consider very carefully any voluntary or planned introductions of flora, fauna or soil to the islands, to subject such plans to rigorous and prior Environmental Impact Assessment, to monitor the effect of the introduction and, whenever practicable, to destroy or remove the introduction once its original purpose is complete.

3. *Recommend*
that particular consideration be given, when considering fishery controls, to the dependence of these terrestrial ecosystems on nutrient input from the Southern Ocean; that marine buffer zones should be instituted (where practicable under extant legislation) to provide some limited protection of food resources;

Encourage
appropriate national authorites to develop agreements for protection of these food chains under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR);

Recognise
that mortality in some bird and seal species during fishing operations or by the ingestion of plastic debris gives cause for serious concern and could be minimised by appropriate national action.

4. *Recommend*
that each national authority develops and implements conservation policies and plans, devised specifically for each island or island group, and incorporating a full consideration of the control of human impact on the natural ecosystem;

Encourage
the implementation of scientific research and monitoring programmes necessary for the conservation management of the island ecosystems;

Recognise
that although achievement of the objectives of conservation plans will be subject mainly to self-assessment, the use of independent observers appointed by each national authority is likely to contribute to greater success.

5. *Recommend*
that island ecosystems as well as specific sites are accorded special legal protection to ensure their integrity is maintained;

Encourage
national authorities to identify a fully representative series of strictly protected areas of restricted access, as well as sites of special scientific interest, and to consider which areas might be proposed for international designation, as World Heritage Sites or Biosphere Reserves, for example.

6. *Recommend*
that organisation and control of stations, logistics and scientific programmes be exercised to ensure minimal impact on the natural ecosystem, and that station development be constrained within a designated area;

Encourage
national authorities to follow the SCAR guidelines on pollution control published for the Antarctic Treaty area.

7. *Recommend*
that historical sites and artefacts of shipwreck, sealing, whaling or other human activities are mapped, documented and conserved as far as possible.

Encourage
the involvement of specialist advisors on archaeology and history in this;

Recognise
that this subject merits detailed treatment outside the remit of this workshop.

8. *Recommend*
that national authorities give immediate consideration to ensuring adequate education for all their island and ship personnel in the conservation objectives for each island in all their island groups;

Encourage
both scientists and administrators to provide public education on the significance and value of the subantarctic islands; encourage responsible and controlled tourism;

Recognise
that SCAR and especially IUCN could make an important contribution to global awareness of subantarctic conservation.

9. *Recommend*
that IUCN convene a meeting of island management authorities to discuss implementation of these recommendations;

Encourage
national authorities, operating agencies and scientists to promote free and full exchange of all information and data, especially on those aspects which concern conservation and environmental protection of these unique islands.

SEALING SITES ON MACQUARIE ISLAND: AN ARCHAEOLOGICAL SURVEY

by K. Townrow

(with five text-figures and three plates)

TOWNROW, K., 1988 (viii): Sealing sites on Macquarie Island: an archaeological survey. *Pap. Proc. Roy. Soc. Tasm.* 122(1): 15–25, 3 pl. Paper presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Department of Lands, Parks and Wildlife, Hobart, Tasmania, Australia.

A brief history of Macquarie Island is outlined with particular note of the different types of sites and sealing equipment used. Their spatial relationships and the evidence for technological change are viewed in the light of this historical evidence. The results of a small excavation challenge the historically derived view that living quarters were continuously repaired and/or re-used. Problems in the management of these resources are outlined.
Key Words: Macquarie Island, sealing, early Australasian industry, early technology, archaeology.

INTRODUCTION

Macquarie Island is a subantarctic island situated in the Southern Ocean at latitude 54°30′S and longitude 158°57′E. It lies approximately 1500 km southsoutheast of Tasmania and 640 km west of the Auckland Islands. The island is approximately 34 km long. Its width varies from approximately 250 m at the Isthmus to a maximum of 5 km. The island is dominated by a central plateau area which is, on average, 150 m high. The coastal fringe offers no good all-weather anchorages. The fauna exploited by the sealers is concentrated on this coastal fringe and includes fur and elephant seals and four species of penguins. The vegetation consists of low shrubs and tussock with no trees. The climate can generally be described as wet, windy, cold-temperate, foggy and humid with a small temperature range.

The cultural remains on the island fall into three categories: shipwreck material, Australasian Antarctic Expedition sites and sealing sites. The sealing sites include living quarters and production sites. Prior to the survey described here, limited work had been conducted on the island by Davies (1982). The current survey was conducted during the five-week Australian National Antarctic Research Expedition (ANARE) summer season in 1986–87. Its main objectives were to survey all the cultural remains on the island, assess their condition and the archaeological potential of the island, and make management recommendations. The survey was funded by a grant from the National Estate, through the Australian Heritage Commission. It was administered by the Department of Land, Parks and Wildlife.

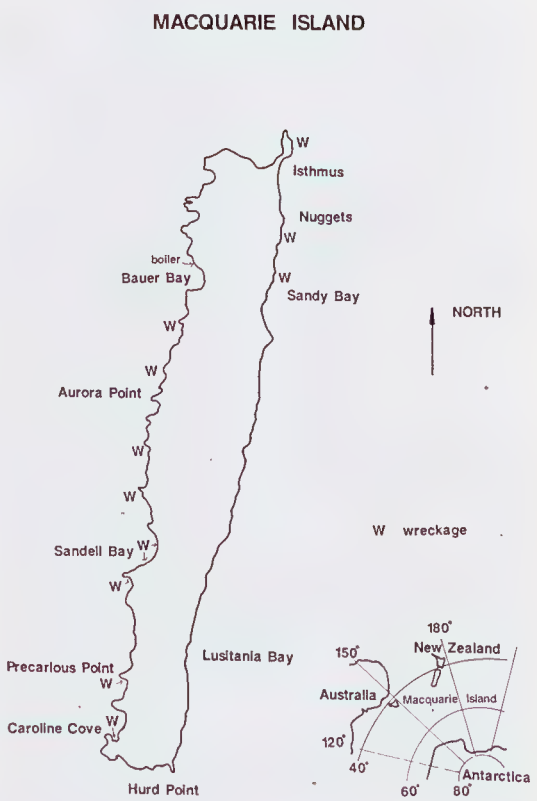


FIG.1 — Macquarie Island, showing sources of cultural remains.

The history of Macquarie Island is an example of the industries of the new colonies, and their technology. Emphasis from the outset was on exploitation, with maximum gain for minimum input, rather than management for maintenance of the resource. This was especially so in the earliest stages. The fur seal population was rapidly devastated and the activity became non-viable; but there was a "fall back". Elephant seal oil production quickly took over and lasted much longer. Penguins were exploited for a short period of time later. Initially the production of oil was by tryworks. This type of technology was crude and inefficient but productive. The more efficient digester technology was only introduced about 80 years later, under the management of one man, Joseph Hatch, who may have been thinking about a more long-term industry, rather than the "hit and run" style of his predecessors.

HISTORICAL BACKGROUND

Macquarie Island was discovered in 1810 by Captain Hasselborough of the *Perseverance* while seeking fur seals (this, and other references in this section, from Cumpston (1968)). A gang was landed in July 1810 to assess the potential of the fur seal population and start harvesting. They considered the potential to be good and tried to keep secret the location of the island, but they failed and by December 1810 a further three gangs had been landed. One of these started rendering down elephant seals, in addition to hunting fur seals. At this stage, gangs appear to have comprised about twelve men. The earliest record of a hut was of one built from the sails and skins salvaged off the wreck of the *Campbell Macquarie* in 1812, but it was soon accidently burned down. The visit of the *Mary and Sally* in 1813, however, indicates that there were huts at the Isthmus, as a gang of eleven men was landed. Tryworks had certainly been established, as men were sent ashore to put them in order (Cumpston 1968, p.30). This party also established living quarters and a tryworks at Sandy Bay.

It appears that the island was then worked seasonally by two to three gangs until the late 1820's. Underwood and MacQueen were the main operators. Huts and tryworks were located at the Isthmus, Sandy Bay, Lusitania Bay and Caroline Cove. It is not clear when the Hurd Point tryworks were first established, but graves dating from 1821–26, described by Cook in 1851, would suggest a starting point. Bellingshausen (a Russian explorer) mentioned separate gangs, totalling 40 men, working the island during his visit in 1820. By that time, the only industry appears to have been elephant seal oil production.

Fur seals were slaughtered to the point of virtual extinction within five years. Records of the number of pelts taken are contradictory, but it certainly exceeded 150 000. Both historically and archaeologically, very little evidence has been found to substantiate the location or locations of this industry on the island.

Underwood ceased operations in 1828 and McQueen in 1829. Bellingshausen's description of the headman's hut at Sandy Bay (Cumpston 1968, p.45) provides an idea of the type of dwellings being used on the island at this time. It was

> "20 feet long by 10 feet broad, inside it was lined with skins of seals, the outside was covered with a kind of grass which grows on the island. At one end there was a small hearth, and a lamp was always kept alight. Beside the hearth was a bedstead. Provisions were stored at the other end of the hut."

Windows are described as bladders stretched over holes in the wall. Carpenters had been employed in various gangs, and it is assumed that timber brought down on ships (and perhaps some shipwreck material) was used to form, at least, a framework for the hut. From 1830 to 1874, there are only records for three trips to Macquarie Island. John Cook's gang of 14 men worked the North End in 1851. His diary provides an insight into the scale of operations in former times. He mentions huts and old casks at a place that appears to have been Unity Bay, and describes the South End works as consisting of houses, tryworks, two cooper's shops and seven graves. Of North Head he states (Cumpston 1968, p.78) that

> "Our flat seems to have been where the most business has been done. Over one dozen old houses and a great quantity of bones and ... hoops (are) buried here; there are Tri-pots set all about in different places; there are 2 graves on the flat ...".

Between 1860 and 1873 there are no shipping records of visits to Macquarie Island at all. There was a brief period of greater interest in elephant seal oil production between 1874 and 1884 by Nichol and Tucker, followed by Cormack, Elder and Co. Activity appears to have been concentrated initially between the Isthmus and Sandy Bay, with repairs and additions to huts. Existing trypots were re-used with relocation of some to Nuggets Creek. Cormack, Elder and Co. gradually extended operations over the ten-year period to include

Lusitania Bay and Hurd Point. Gangs were generally smaller than in early years, averaging eight men.

Intermittent working continued on the island until 1889 when Joseph Hatch began to dominate operations. Hatch was a New Zealand entrepeneur who became involved in the trade initially to supplement his pharmaceutical business. He had gangs of about eight men operating on the island for the next 30 years. During this period, the transition was made from a low-technology, small capital operation to a more intensive and expensive industry. Headquarters were initially at Lusitania Bay. Here, elephant seals were rendered down and the exploitation of the king penguin colony began. Digesters were introduced at Lusitania in November 1889. Coal, timber and firewood then became regular items on the list of stores taken to the island. Depots in other parts of the island were also used. For example, the *Gratitude* collected oil from North End, South End and Lusitania Bay in February 1891.

In early 1892, Hatch's headquarters were transferred to the Nuggets. A gradual transition from the exploitation of king penguins to royal penguins also seems to have begun. This was possibly because of the problems of fermentation of the king penguin oil, since it had not been possible to reduce the blood content in it, and/or too great a reduction in king penguin numbers. Digesters and boilers were also set up at the Isthmus, Hurd Point and Hasselborough Bay. The industry then settled into a two-part operation conducted in two seasons: the royal penguin season operated from the Nuggets during November and December and the elephant seal season operated from North Head from mid-August until the end of October. Hatch's confidence in being able to maintain a continuing operation on Macquarie Island seems to be reflected in the introduction of digester plants. He also secured a sole occupational licence in 1902.

However, opposition to his operation began during the 1910's. Headed by Mawson, who had led the 1911–14 Australasian Antarctic Expedition, a campaign to declare the island a nature reserve and to condemn the royal penguin industry, in particular, gained momentum. After a brief respite in this campaign, during World War I, it seems to have become somewhat inflammatory. Claims, often by people who had never been to the island, became increasingly exaggerated. Despite continual public denials by Hatch of these exaggerated claims, he was finally forced, through the cancellation of his licence, to cease operations in 1920. Even without this cancellation, he might not have been able to continue, due to increasing financial difficulties.

ARCHAEOLOGICAL EVIDENCE

An archaeological survey of the island was undertaken in late 1986–early 1987. The sealing activities have left three main categories of remains; shipwreck material, living quarters and two types of production sites. Although all categories are interrelated, they are not necessarily all represented at every site. Living sites are distinct from production sites, in that they contain either tryworks or steam digester plants. There would appear to have been little or no intermingling of the functional use of the huts.

Shipwreck Material

Without diving it was only possible to observe the material which has gathered along the coastlines in the form of flotsam and jetsam. This is mixed with some of the refuse of the Southern Ocean. The material is concentrated on the east coast between North Head and Sandy Bay and right along the west coast. The east coast scatter is undoubtedly related to the concentration of known shipwrecks in this area. The scatter on the west coast is probably attributable to its windward location, in the path of the general drift of the Southern Ocean. The last obvious remains of the *Gratitude*, which was beached at the Nuggets, were carried out to sea in 1975–76 (G. Copson, pers. comm.).

Living Quarters

Quarters can be found at the Isthmus, the Nuggets, Lusitania Bay and Hurd Point. There are possibly remains of living quarters at Sandy Bay but they have deteriorated to the point of being nebulous.

Three huts were identified at the Isthmus. All are located under the eastern lee of Razorback Hill. Associated with these huts was a large scatter of artefacts, including parts of an iron stove, a clay tobacco pipe bowl, barrel staves and assorted timber.

The Nuggets living quarters consist of a large and small hut. The larger is more clearly defined by a row of large beach stones on its seaward side. The layout of floorboards at this hut suggests that the smaller, sleeping area was at the northeast end of the hut with a larger, communal/store area at the other. Adjacent to the western corner of the hut is a

FIG.2 — Isthmus living quarters, showing location of artefacts.

PLATE 1
Hurd Point tryworks, an example of the problems of archaeological survey during the penguin breeding season.

small outhouse, which may have acted as an extra store or pantry area. The small living quarters are defined by some corner posts. Associated with the huts are parts of a stove, a standing mooring post, bricks, a mallet head and bottle glass fragments.

Both the Hurd Point and Lusitania Bay living quarters were almost totally obscured when fieldwork was being conducted, because both sites are situated within large royal or king penguin colonies (plate 1). However, one living hut was positively identified at each site. The Hurd Point hut lies on the western edge of the colony, perched half-way up the beach bank. As with the Isthmus huts, it had stilts on the seaward side. The Lusitania hut was much smaller than the others and, at this stage, could only be identified by four corner posts, an anvil, barrel base and timber scatter.

Production Sites

These can be divided into two types: trypot works and digester works. Evidence of tryworks is present at Hurd Point, Caroline Cove, Lusitania Bay and the Isthmus. Of these sites, Hurd Point is the most intact example, with a cluster of six trypots and the scattered remains of three others in the general vicinity. The cluster of trypots is arranged so that one feeds into two. Two such groups are positioned north-south down the beach bank. Remains of a building which housed these works are present. At the other sites, tryworks are represented by two trypots at Caroline Cove, one of which is three-quarters buried; one at Lusitania Bay with associated timber; and one at the Isthmus, almost totally buried.

Digester works can be found at the Isthmus, the Nuggets, Hasselborough Bay, Lusitania Bay and Hurd Point. Both Hurd Point and Hasselborough Bay have only one small digester and one boiler. Remains of the sheds which housed them are evident at both locations. Lusitania Bay has one small and one large digester (plate 2) and a boiler, which were all originally housed in a large shed. The Nuggets has a group of two small and two large digesters fed by three boilers within a shed. Two discarded boilers lie to the southwest of the site. The Isthmus works consist of two digesters, one boiler, and a discarded boiler to the east of the site. Both these sites also have the foundations of the sheds which housed them. Artefacts associated with this type of site include tools, such as vices and anvils, barrels, coal and settling tanks. The Nuggets and Lusitania Bay sites both appear to have piped in water to the boilers. At the Nuggets, there are two stationary pumps which would have been used for this purpose.

PLATE 2
Lusitania Bay, steam digester plant.

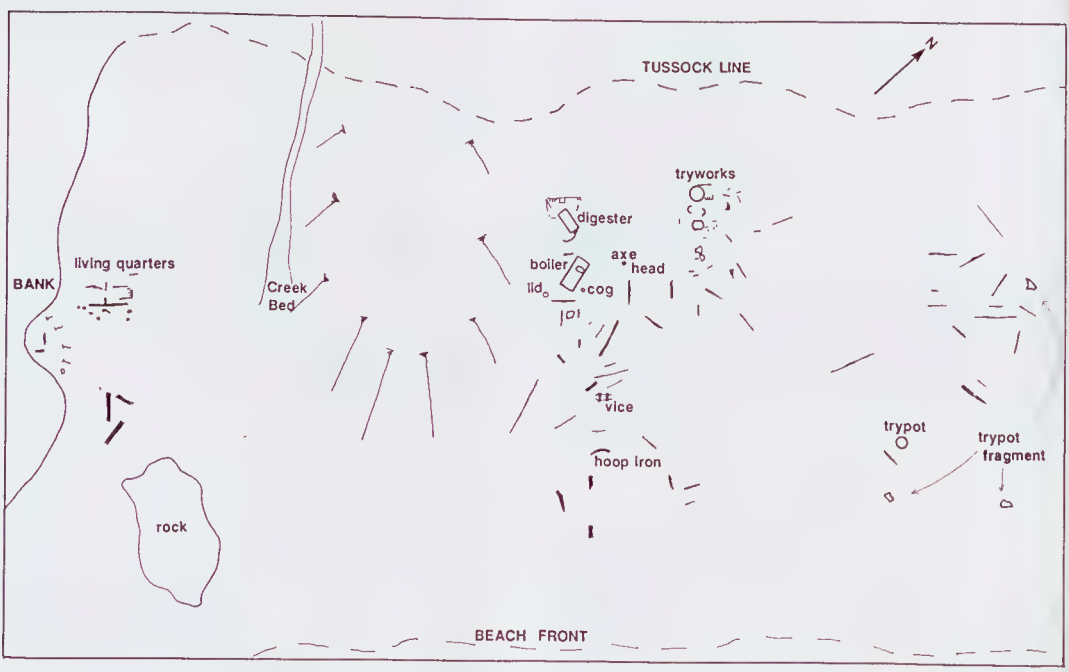


FIG.3 — Hurd Point production site, showing location of artefacts.

EXCAVATION

A 1 m by 6 m trial trench was excavated through one of the huts at the Isthmus (plate 3). The excavation was conducted in an attempt to determine the effectiveness of this form of investigation on the island. The specific site was chosen because the hut was known to have been used by Hatch's men in the 1910's (archival photographs), thereby providing an end-date to occupation at this site. Hence it could be more reliably assessed whether the hut represented the re-use of an earlier construction. The trench was orientated to run east-west, covering what was thought to be the side of the structure. Standard archaeological procedure was followed, although the soil was not sieved for artefacts.

The trench established that considerable quantities of material are being obscured by vegetation. The main location of this material was just beneath the regrowth which has been the principal agent in its preservation. Unfortunately the trench did not expose the side of the hut but appears to have uncovered a "cold porch" or workshop area where tools and the horse harness could have been stored. The horse was undoubtedly one of the Clydesdales used by Hatch's men to pull the blubber sled, during the later phase of his operations. Only the floor joists and posts with some wall planking, complete with tar (bitumen insulation) paper, remained of the hut. It, therefore, seems likely that the floorboards were scavenged at a later date and perhaps used to repair other buildings or as fuel. The hut appears to have been stilted to the east (this is confirmed by archival photographs). It was not possible to determine whether the hut had been refurbished (the trench proved to be too small), although it may not have represented an original 1820's hut, since a penguin bone refuse pile was found under the floor joists which may pre-date the hut. The total depth of occupation at the western end was 1.1 m. It was generally found that the state of preservation of the artefacts was good. Leather, iron, fabric and wood artefacts were in reasonable condition, although, due to the acidity of the soil, bone artefacts were not as well preserved. The finds included a cart-horse harness, various iron tools, guttering, wall insulation, glassware, domestic pottery, elephant seal teeth, two spent cartridges from different calibre firearms and parts of a cupboard or tea-chest.

PLATE 3 — Trial trench, Isthmus living quarters, after removal of vegetation.

DISCUSSION

From this evidence the following comments can be made:

(1) Where living quarters and production sites are found at the one location, the living quarters are situated 25–50 m upwind of the production sites, unless confined by topographical restraints (for example see fig. 3). The reason for this seems to be purely one of relative comfort. The smell of rancid blubber from the boiling process was notorious.

(2) Living quarters appear to have a rather limited life. No evidence was found of the early tussock-with-wood frame huts. Remains of huts were identified at the Isthmus, some of them possibly from the dozen huts described in 1851, but none could be positively established as such. The historical records mention constant repairs to huts, but the limited excavation undertaken suggests that the same huts were not continuously repaired.

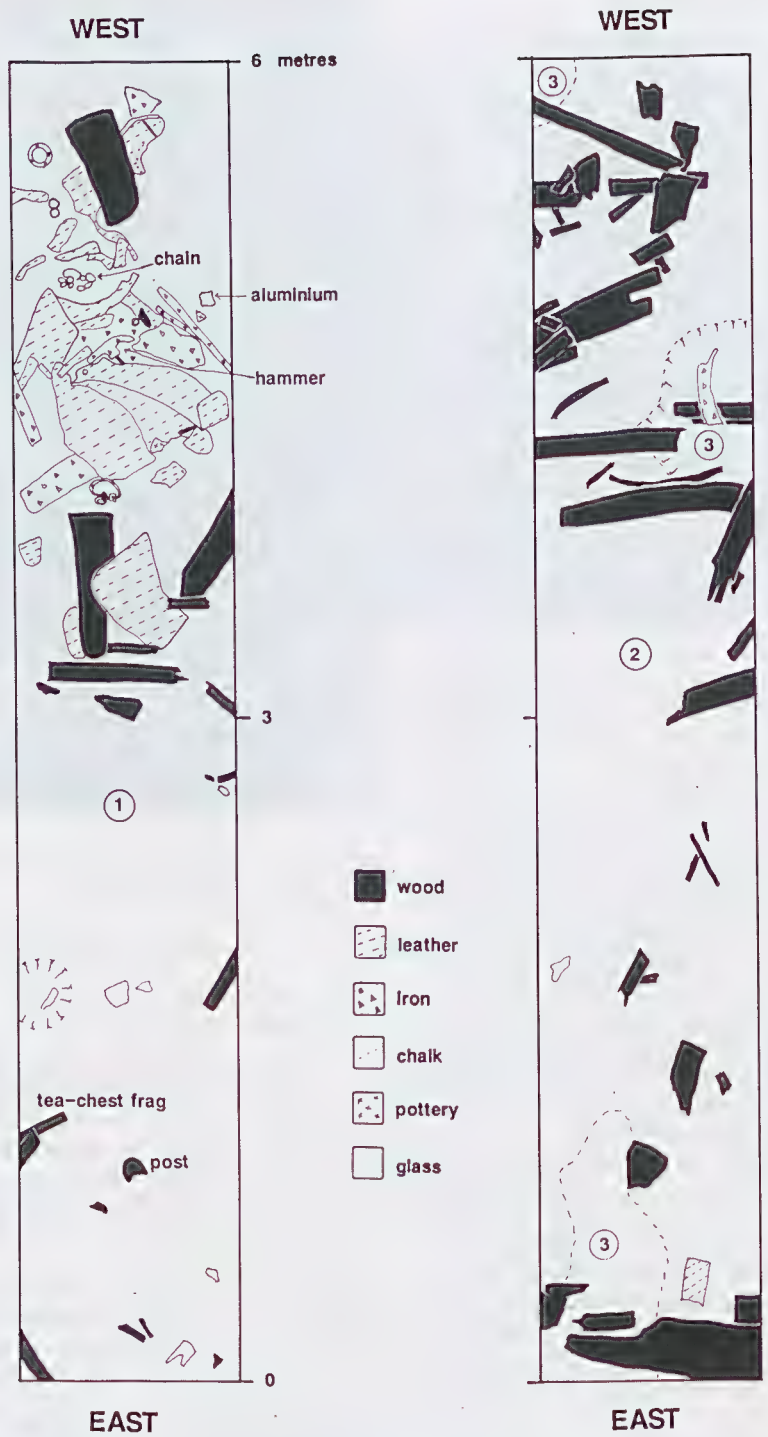


FIG.4 — Isthmus test trench — horizontal layout; numbers refer to different levels of excavation.

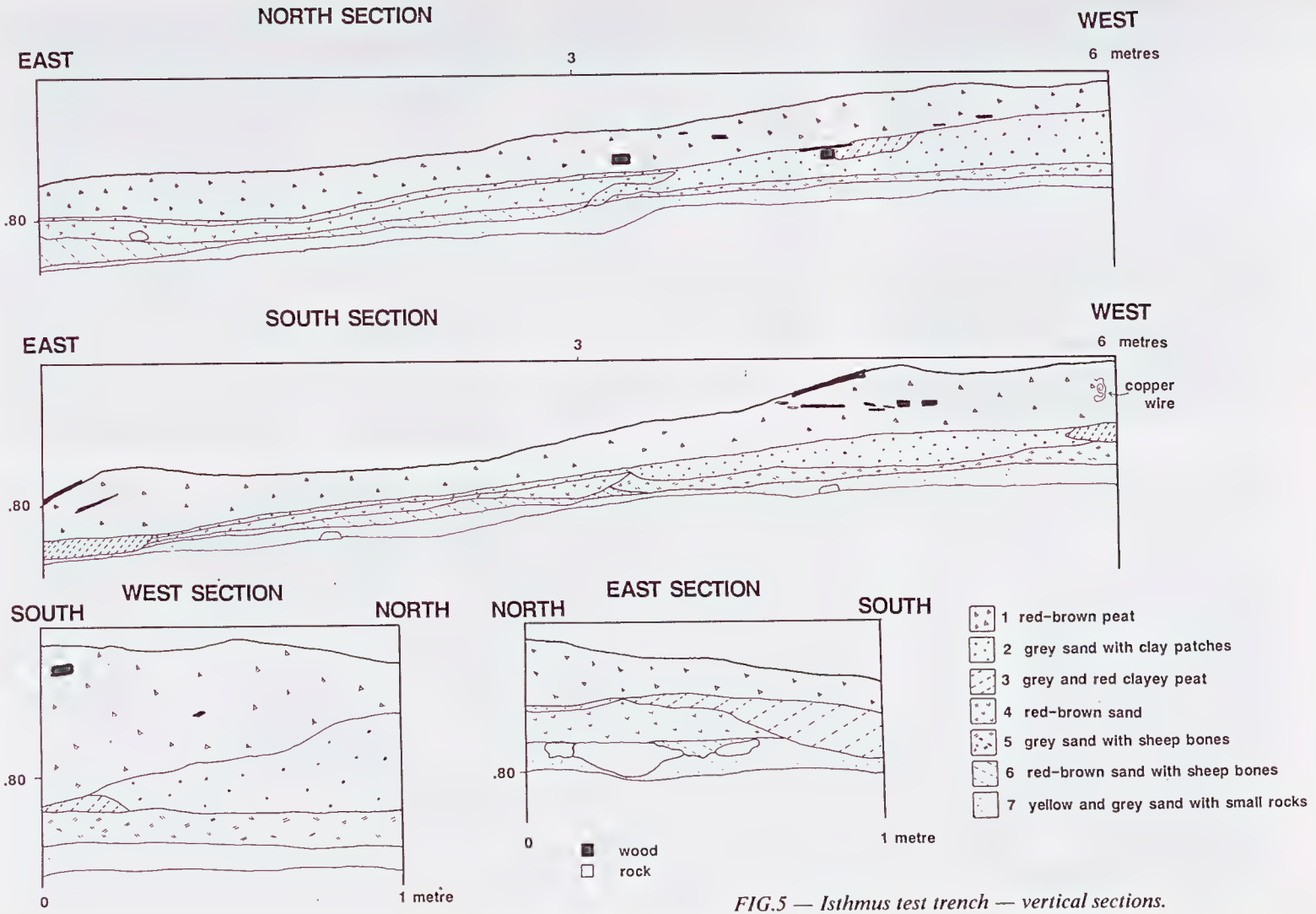


FIG.5 — Isthmus test trench — vertical sections.

Instead, when a hut was beyond repair, material was salvaged and re-used in building a new hut in a new location. However, additional excavations would need to be carried out to confirm this or highlight differences between sites.

(3) The tryworks reflect the longer industrial phase and have consequently suffered the most from re-use and/or relocation of the pots from their original situations. The loss of context of any artefact is directly related to its portability. The trypots, being relatively portable, compared to boilers and digesters, have been more subject to this problem.

(4) The trypots show no uniformity of size or design. They have little, if any, decoration. This reflects the low level of technology required for the boiling-down process.

(5) This simple technology was in use during the peak period of production between 1810 and 1830 (Hindell & Burton, this volume). The obvious reason contributing to the relative success of this technology, compared to the "higher technology" of steam digesters, was greater availability of the resource, but other factors may have contributed, such as higher labour input per gang and, in total, stimulus of rivalry between gangs or the stimulus of higher profitability.

(6) The use of digesters in the production of seal and penguin oils would appear to be unique to Macquarie Island. It is likely that they were adapted from similar plants used on whaling boats to render down blubber. In the whaling industry, similar types of digesters, of Norwegian design, were in use by 1889 (Tonenessen & Johnsen 1982). At the time of their introduction on Macquarie Island, at Lusitania Bay in 1889, therefore, they may have been "state of the art".

(7) The digesters appear to represent two phases of development; the smaller and single sets representing the trial usage and the larger representing the more cost efficient locations for this type of machinery. Size may also be related to the resource being used. The larger digesters are present at the Nuggets and Lusitania Bay, indicating that a larger size of digester was viable where large numbers of easily obtainable penguins were available, but was not necessary or viable when rendering down elephant seal blubber.

(8) The digesters and boilers represent an increasing availability of large manufactured machinery during the late nineteenth and early twentieth centuries. They are standardised in design and manufacture, made from hot-rivetted sheet iron. There are distinct sizes. The digester works, therefore, may be said to reflect the rapid changes in industrial technology in the Australasian colonies during this time.

(9) The sites represent entrepreneurial activity rather than a Government-initiated or subsidised industry. As such, the remains tend to reflect their functional and essentially temporary nature rather than any degree of permanence. Equipment was left where it stood because it was not a profitable proposition to remove it.

(10) The sites may also be a reflection on general work and living conditions in Australia and New Zealand during the last century. Conditions on Macquarie Island were always harsh, yet men were prepared to work there, often for relatively long periods. This would suggest that either there was not a sufficient range of job opportunities at home or that conditions were not substantially different or both.

FACTORS AFFECTING THE SURVIVAL OF REMAINS

Factors affecting the rate of attrition of this resource are weather and sea, flora and fauna, and human intervention.

The climate of Macquarie Island is cold, wet and saline. This has resulted in the deterioration of ironwork, the collapse and scattering of huts and the rotting of wood. Storms add to this, with high seas tending to redistribute remains along the coast.

The fauna can be a problem. The survival of remains within penguin rookeries is limited. Seals wallow, and tend to relocate or obscure remains or expose them to the weather. Although the flora, particularly tussock-grass, tends to totally obscure remains, excavation has shown that it may also act as a protective covering, thereby keeping the remains in a damp but relatively stable environment.

Human intervention has possibly been the greatest drain on the resource. Initially, any available salvageable material seems to have been re-used where at all possible. Although this is also part of the archaeological record, it tends to introduce interpretative problems. In later years, the evidence that has retained its context appears to have suffered from souveniring, and from the lack of a policy on what was to be done with the artefacts and the sites. The policy of leaving artefacts *in situ*, unless under immediate threat, was introduced in 1982 and has helped to reduce the amount of preventable damage caused by human intervention.

CONCLUSION

The survey conducted on Macquarie Island during the 1986–87 summer season indicates its potential for increasing understanding of early Australasian industry and technology. The industry and its remains may also reflect some societal attitudes of that time, in regard to the use of primary resources. It is important that the work done in the study is followed up, through additional excavation and by survey, during the non-breeding season, of remains within penguin colonies. Archaeological evidence, by providing additional information and throwing new light on present records, represents the best remaining source of material for understanding the early human activity on Macquarie Island.

REFERENCES

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1). Antarctic Division, Department of External Affairs, Australia.

DAVIES, M., 1982: Macquarie Island: Archaeological Report. National Parks and Wildlife Service Report, unpubl.

HINDELL, M. & BURTON H., 1988: The history of the elephant seal industry at Macquarie Island and an estimate of the pre-sealing numbers. *Pap. Proc. R. Soc. Tasm.* 122(1): 159–176.

TONNESSON, J.N. & JOHNSEN, A.L., 1982: *THE HISTORY OF MODERN WHALING*. Australian National University Press, Canberra.

(accepted 18 September 1987)

ORIGIN, STRUCTURAL AND TECTONIC HISTORY OF THE MACQUARIE ISLAND REGION

by P.E. Williamson

(with eleven text-figures)

WILLIAMSON, P.E., 1988 (viii): Origin, structural and tectonic history of the Macquarie Island region. *Pap. Proc. R. Soc. Tasm.*, 122(1): 27 43. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Bureau of Mineral Resources, Canberra, A.C.T., Australia.

Macquarie Island, in the Southern Ocean, was formed by oceanic crust uplift due to transpressive forces between the Indian/Australian and Pacific oceanic plates, in a transpressional regime which has persisted over the last 10 Ma. The amount of uplift is affected by regional isostatic compensation for crustal thickening; accompanying effects are tilting of rocks and rotation of the southern segment of the island. Gabbro and serpentinite, in the north, and basalts, in the south, all of which were formed in the primary oceanic crust, are now exposed. Consequently, magnetic properties of igneous rocks on the island correlate with similar features on the Indian plate which is on both sides of it.

In conflict with evidence from younger palaeontological and potassium-argon (K-Ar) dating, which may reflect later episodes, this suggests that the original oceanic crust composing the island was formed at the Indian-Antarctic accreting mid-oceanic ridge around the time of anomaly 7 (27 Ma B.P.).

Key Words: oceanic crust uplift, magnetic anomalies, sea-floor history, Macquarie Island.

INTRODUCTION

The tectonic and physiographic expression of Macquarie Island and the surrounding region (fig. 1) is the result of oblique compression (transpression) between the Indian/Australian and Pacific oceanic plates near to their common boundary. This boundary, south of New Zealand, lies within the Macquarie Ridge Complex, an arcuate system of ridges and troughs, extending from the Macquarie triple junction between the Indian, Pacific and Antarctic plates near 62°S, 160°E (Sykes 1970) to the Alpine Fault of the South Island of New Zealand. The major physiographic element of the complex is an arcuate ridge (the Macquarie Ridge) with a trench (the Macquarie Trench) to the east in the central area and a trench to the west in the northern area (Puysegur) and the southern area (Hjort).

Geological and geophysical studies of the Macquarie Ridge began with the New Zealand programme to investigate the marine geology of the New Zealand subantarctic sea floor (Summerhayes 1969). Reconnaissance geophysical investigations in the region were later carried out by Lamont-Doherty Geological Observatory vessels *Vema* and *Conrad*, and were expanded between 1968 and 1971, using the USNS *Eltanin*. Data were also collected during a cruise by the Japanese vessel *Umitaka-Maru* and during aeromagnetic studies by the US Navy Oceanographic Office. In the Macquarie Island region, marine magnetic and bathymetric data were collected, primarily by the author, from the Australian National Antarctic Research Expedition (ANARE) relief vessel *Nella Dan* between 1970 and 1973.

Magnetic lineations have been used to resolve the sea-floor spreading history between Australia and Antarctica (Weissel 1972, Weissel & Hayes 1971, 1972, Weissel *et al.* 1977) and in the Pacific plate south of New Zealand (Christoffel & Falconer 1972). The broad crustal structure and tectonic history of the Macquarie Ridge Complex and the Macquarie Island region has been discussed by Hayes & Talwani (1972), Woodward (1973), Williamson & Johnson (1974), Williamson (1974, 1975), and Weissel *et al.* (1977), utilising a predominantly marine geophysical data base, and by Ruff & Cazenave (1985), using SEASAT data.

Analyses of sea-floor spreading magnetic lineations and gravity from Macquarie Island imply that the origins of the rocks of Macquarie Island were mainly at the Indian/Australian-Antarctic spreading centre, probably around 27 Ma B.P. — anomaly 7 time (Williamson 1974, 1978, Williamson *et al.* 1981). Subsequent rotation of island segments, probably during uplift of Macquarie Island, has been demonstrated by Williamson (1978) and Varne & Rubenach (1972).

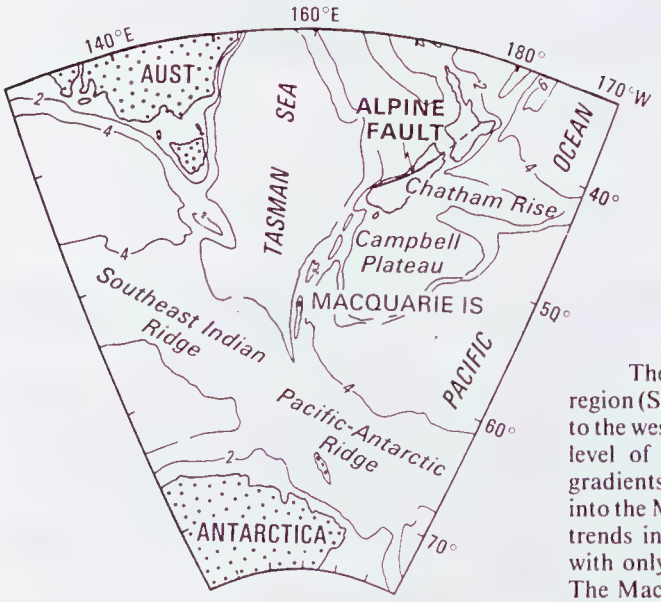


FIG. 1 — Locality map. Isobaths at 2, 4 and 6 km.

This paper represents a review, and, for the palaeomagnetic component, a reassessment of the geophysical and geological studies relating to the broad structure and origins of the Macquarie Island region, as a basis for future study.

MORPHOLOGY

Macquarie Ridge Complex

The morphology of the major segments of the Macquarie Ridge Complex (figs 2 and 3) has been described earlier (Brodie & Dawson 1965, Summerhayes 1969, Hayes & Talwani 1972). Except for a number of breaks (sometimes pronounced), the ridge lies at a depth less than 2000 m between latitudes of 47°S and 57°S. South of 57°S it becomes less regular and branches into two segments. The Macquarie Trench lies east of the Macquarie Ridge between about 51°S and 56°S. It is a continuous deep over a distance of 550 km. It reaches a maximum depth of 6000 m and is typically deeper than 5200 m.

The Emerald Basin, east of the Macquarie Trench, is characterised by numerous large seamounts and pronounced depressions, especially in the vicinity of 55°S–59°S (Hayes & Talwani 1972). The basin lying to the west of the Macquarie Ridge is characterised by relatively low relief, generally less than 400 m, and variable sediment thickness (Houtz et al. 1971, Hayes & Conolly 1972).

Macquarie Island Region

The bathymetry of the Macquarie Island region (Summerhayes 1969) shows gentle gradients to the west of the island which continue down to the level of the ocean basin (fig. 3). Much steeper gradients occur to the east of the island and extend into the Macquarie Trench. The major bathymetric trends in the area parallel the Macquarie Ridge, with only minor irregularities along these trends. The Macquarie Ridge is consistently shallow and rises above sea level in the cases of Macquarie Island, Bishop and Clerk Islands to the south, and Judge and Clerk Islands to the north.

Macquarie Island itself trends northnorth-easterly, paralleling the Macquarie Ridge in the region. The island is characterised by a narrow coastal strip with steep slopes up to an undulating plateau at a maximum elevation of about 400 m. The island plateau is cut by a major valley between Bauer Bay and Sandy Bay.

GEOLOGY

Macquarie Ridge Complex

Dredge hauls along the Macquarie Ridge (Summerhayes 1969, Watkins & Gunn 1970) obtained *in situ* tholeiitic basalt, harzburgite, peridotite, sodic olivine gabbro and troctolite, similar to such rocks observed on Macquarie Island. The Macquarie Ridge Complex south of 51°S appears from these data to be composed of rocks similar to normal oceanic crust.

The Macquarie Ridge is virtually devoid of sediment cover, and sedimentation in adjacent areas is extremely variable (Houtz & Markl 1972, Houtz *et al.* 1971, Hayes & Talwani 1972). The sediments in the Macquarie Trench are generally variable in thickness (from zero to 1 km) but are locally undisturbed and horizontally layered (Hayes & Talwani 1972), with thick accumulations of sediments occurring in small enclosed basins (Houtz *et al.* 1971).

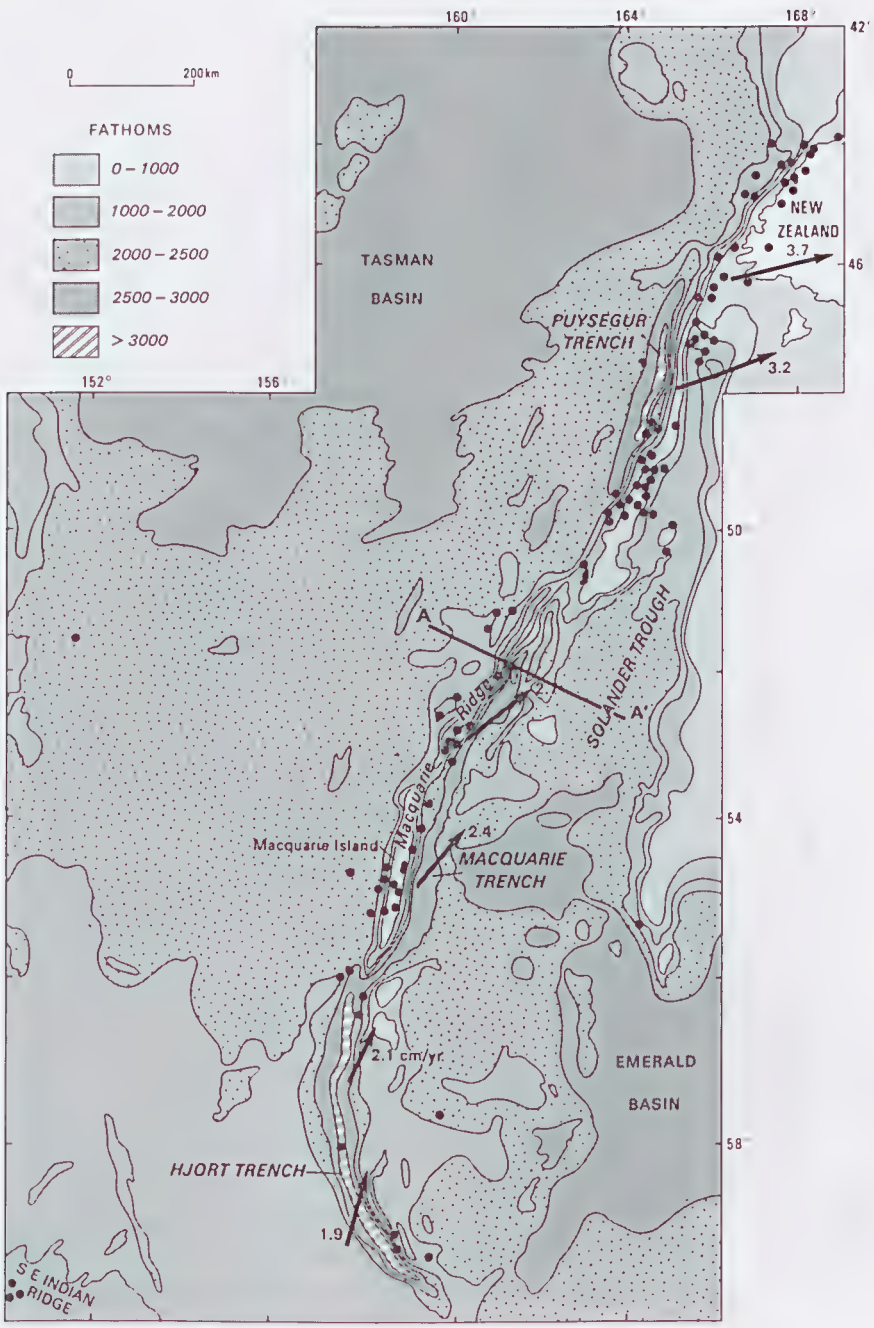


FIG. 2 – Generalised bathymetry of the Macquarie Ridge Complex showing seismicity (after Jones & McCue, this volume) and vectors of relative plate motion of the Indian/Australian and Pacific plates in cm/yr (after Minster & Jordan 1978); A–A' is the location of the gravity profile shown in figure 6.

FIG. 3 — Bathymetry of the Macquarie Island region contoured in metres (after Summerhayes 1967).

Macquarie Island

Early work carried out on Macquarie Island by Mawson (1943) has largely been superseded by more detailed work (Varne *et al.* 1969, Varne & Rubenach 1972, Quilty *et al.* 1973, Griffin & Varne 1980, Griffin 1982, Christodoulou *et. al.* 1984). Varne & Rubenach (1972) concluded that the island is formed of fault-bounded blocks. The northern part of the island is described as composed mainly of serpentinised peridotites, gabbros, and dolerite dyke swarms (fig. 5), and the southern part of extrusive rocks (fig. 4) which occur both as basaltic lava and as basaltic volcanic breccias. Parallel dolerite dykes cut the lavas, volcanic breccias and associated sediments in all parts of the island, but there is no continuous gradation from areas of extrusive rocks cut by dykes into the areas of dyke swarms. Globigerina ooze occurs as interstitial materials in the pillow lavas, and poorly preserved coccoliths have been found at North Head.

The detailed structure and stratigraphy of the extrusive rocks of the island are complex and poorly understood. The pillow forms of some lavas imply that these have been tilted or near-vertical attitudes, but the steepest dips which could be reliably measured on lava flows with interbedded mudstone are about 45°. These flows were presumably horizontal or near-horizontal at the time of deposition. Many high and low angle faults cut the extrusive rocks.

Dykes cut the interbedded lava flows, breccias and sediments as a series of parallel sheets and do not intersect one another. Acute angles between the planes of the dykes and the bedding planes of the extrusive rocks are almost always large, no matter how steep the inclinations of the bedding planes, implying that the dykes were originally steeply inclined intrusions into relatively flat-lying extrusive rocks, and that the tilting occurred subsequently. In addition, the strikes of the tilted lava flows, breccias, and sediments are parallel or near-parallel to the strikes of the dykes that cut them. Seemingly, therefore, the axes about which the tilting took place must have been approximately horizontal and parallel to the dyke-bedding plane intersections (Varne & Rubenach 1972).

In the northern part of the island, coarse-grained intrusive rocks representing deeper levels in normal oceanic crust are exposed. The serpentinised peridotites are usually massive rocks. The only layering interpreted as compositional occurs at Eagle point, where adjacent layers differ in their proportions of serpentinised olivine and ortho-

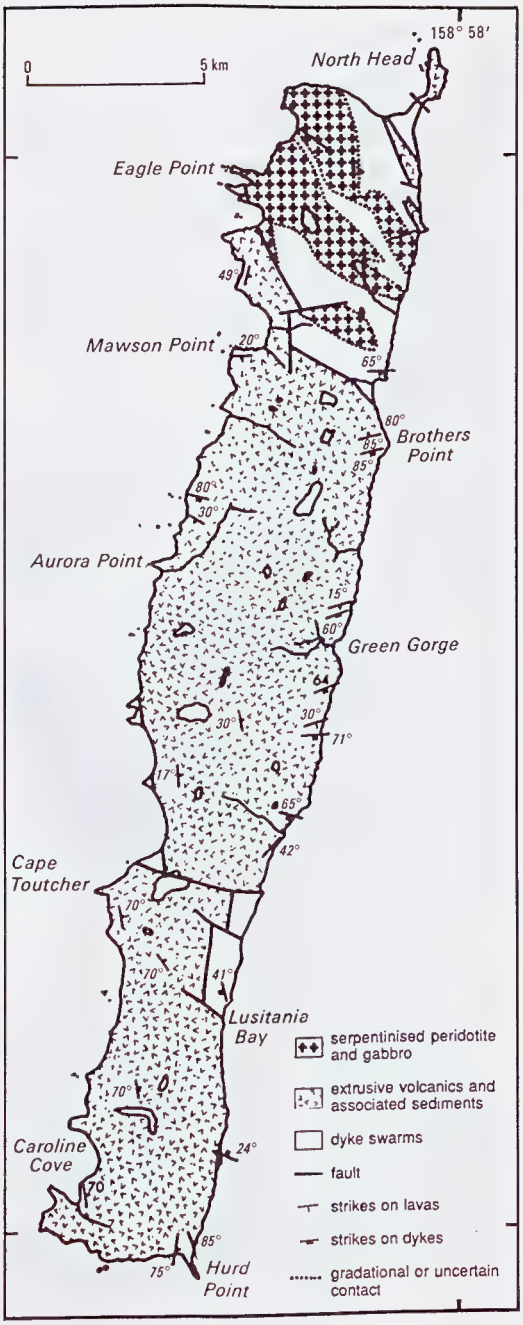


FIG. 4 — Generalised geological map of Macquarie Island with superficial deposits omitted (after Varne & Rubenach 1972).

pyroxene. The style and regularity of this layering are similar to that found in cumulate rocks, and the layers are continuous over the length of the outcrop. A layered gabbro complex disturbed by faulting and dyke swarm emplacement occurs in the north-west section of the island, and large outcrops showing spectacular layering are exposed.

Varne & Rubenach (1972) argued that the lack of schistosity or penetrative cleavage in the metamorphosed basalts and dolerites in the north of the island, and the survival of igneous textures, indicate that the metamorphism was not accompanied by deformation, and was similar in nature to burial metamorphism.

Petrographic analyses of rocks from Macquarie Island by Varne & Rubenach (1972) show the majority of the dolerites and basalts are similar to normal ocean crust. On the basis of trace element studies, the rocks from Macquarie Island also clearly correspond to the ocean-floor basalts, although some variation in the trace element content in the rocks occurs (Varne & Rubenach 1972, Griffin & Varne 1980).

Although Macquarie Island geologically forms part of the crest of the Macquarie Ridge, the rocks of the island were not, in general, formed during tectonic evolution and emergence of the ridge within the last 10 Ma. This is supported by the observation that some of the freshest and presumably youngest volcanic rocks on Macquarie Island are associated with sediments that appear to be of Miocene age (11–25 Ma) (Quilty *et al.* 1973).

CRUSTAL STRUCTURE AND TECTONIC HISTORY

During the last 10 Ma and up to the present time, the dominant motion between the Indian/Australian and Pacific plates south of New Zealand has been interpreted as mainly transcurrent, with compression particularly at the Hjort and Puysegur Trenches, where varying degrees of nascent subduction of the Indian plate are indicated from earthquake studies by Banghar & Sykes (1969) and from studies of relative plate motion by Weissel (1972), Hayes & Talwani (1972), Hayes *et al.* (1972) and Weissel *et al.* (1977).

Seismicity

Studies of the seismicity of the Macquarie Ridge Complex have been made by Cook (1966) and Barazangi & Dorman (1969). Seismic epicentres (Barazangi & Dorman 1969, Jones & McCue, this volume) show zones of intense activity at the southern end of New Zealand, between about 49° S and 53° S, and at about 56° S. First motion studies have been made on events from the Macquarie Ridge by Bangar & Sykes (1969), Sykes (1967, 1970), Johnson & Molnar (1972), Ruff *et al.* (1982) and Jones & McCue (this volume). Results of Johnson & Molnar (1972) indicate that underthrusting of the Tasman Sea exists along the Macquarie Ridge Complex south to about 52° S. Dextral strike-slip motion is interpreted on a fault plane approximately parallel to the Macquarie Ridge at 56.2° S while, for an event at 57.5° S, formal faulting is interpreted. Jones & McCue (this volume) show dextral strike slip motion for the Macquarie Island region.

Johnson & Molnar (1972) concluded that the pole of rotation of the Australian–Pacific plate is located east of and close to the ridge, at about 56–57° S. Ruff *et al.* (1982), however, have generated focal mechanism solutions, in basic agreement with the globally derived RM2 rotation pole of Minster & Jordan (1978), that place the pole at 60.5° S and imply transpression of varying degrees for the whole Macquarie Ridge complex. That compression along the plate boundary is a recent activity is supported by the plate tectonic reconstruction of Molnar *et al.* (1975) and the studies of Walcott (1978) and Scholz *et al.* (1973). These studies indicate that, prior to 10 Ma B.P., the Macquarie Ridge was characterised by strike-slip and spreading motions.

Gravity

The gross crustal structure associated with the central Macquarie Ridge Complex has been investigated using gravity data. Marine gravity data over this area have been inverted to show a progressive thickening of the Indian/Australian oceanic crustal layer from approximately 7 to 14 km, over a 200 km distance as the ridge is approached from the west (Williamson & Johnson 1974). A root zone, some 30 km wide and approximately 4 km thick, is indicated not symmetrically beneath the Macquarie Ridge itself but displaced towards the trench. Another root zone, approximately 50 km wide and 3 km thick, within the Emerald Basin to the east of an unthickened segment of oceanic crust immediately west of the Macquarie Trench, appears to be associated with a local bathymetric high, possibly caused by volcanic activity (Hayes & Talwani 1972) or the presence of an ancient spreading ridge associated with the opening of the Emerald Basin.

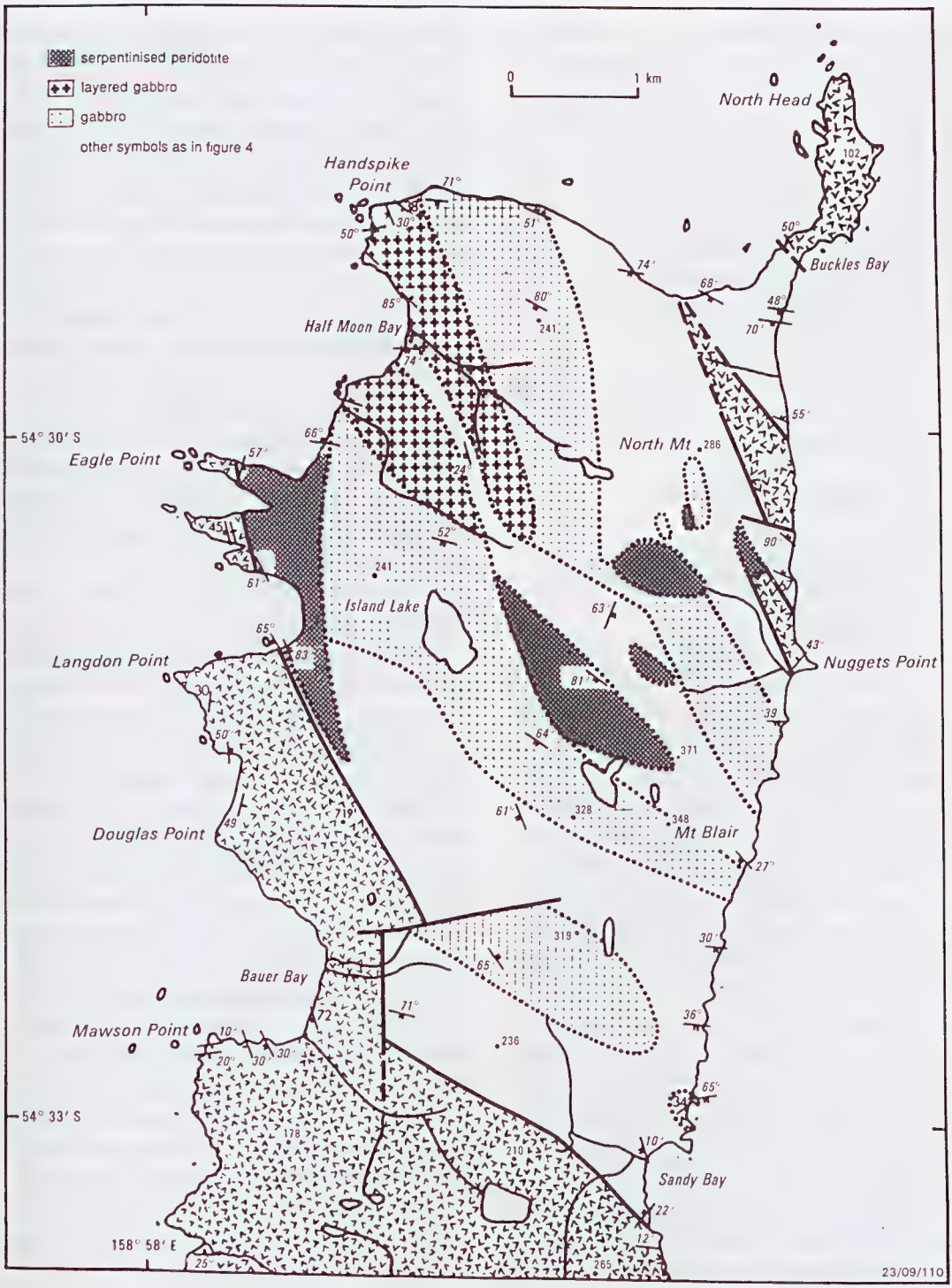


FIG. 5 — Geological map of the northern part of Macquarie Island with superficial deposits omitted (after Varne & Rubenach 1972).

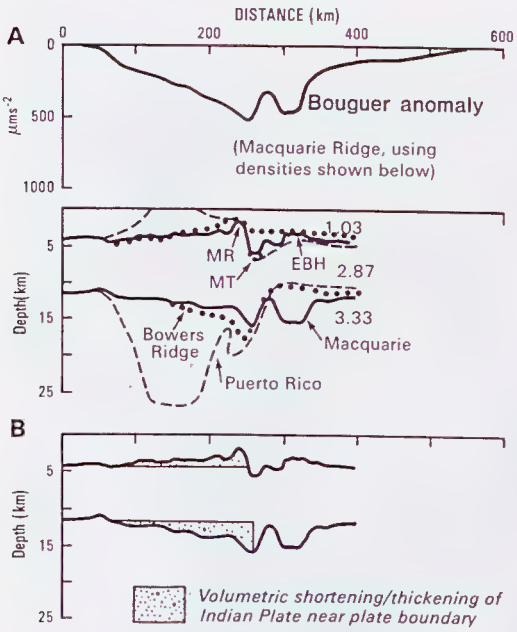


FIG. 6 — (A) Crustal structure (lower surfaces) over the central Macquarie Ridge Complex, arrived at by inversion of Bouguer gravity anomaly data, and bathymetry (upper surfaces); demonstrating incipient subduction compared to progressively more developed subduction for the Bowers Ridge and Puerto Rico Trench region. MR is Macquarie Ridge; MT is Macquarie Trench; EBH is Emerald Basin High. Densities used for the inversion are also shown. Location of profile is shown in figure 2. (After Williamson 1975.) (B) Stippled area shows the crustal thickening relative to the original Indian/Australian oceanic plate during the formation of the Macquarie Ridge, which could accommodate crustal shortening of 65 km.

Asymmetry similar to that observed for the central Macquarie Ridge (excluding the Emerald Basin feature) is typical of island arc systems (fig. 6). The Tonga–Kermadec area has been investigated by Talwani *et al.* (1961), the mature Puerto Rico Trench region, by Talwani, Sutton & Worzel (1959), the nascent Bowers Ridge Complex by Kienle (1971), and the Japan region by Tomoda (1973). All the above regions exhibit asymmetry in the free air and Bouguer gravity anomalies, and in their inferred crustal structure. Also, in island arc regions, negative isostatic anomalies are associated with the trench and positive isostatic anomalies with the arc or ridge (Heiskanen & Vening Meinesz 1958, Tomoda 1971). Similar relationships are observed for the Macquarie Ridge Complex (Hayes & Talwani 1972). For well-developed island arc systems, such as that associated with the Puerto Rico Trench (Talwani, Sutton & Worzel 1959), where extensive loading by island arc volcanics has occurred, this asymmetry is not as marked as it is in the case of partially developed systems, such as in the western part of the Bowers Ridge. In the latter area, crustal thickening increases towards the trench, with the root zone occurring beneath the trench. This is most similar to that observed for the central region of the Macquarie Complex. A similar, though less pronounced, crustal structure occurs in the Mendocino Escarpment, where a root zone is present and is displaced from the bathymetric high towards a buried trough feature masked by thick sediments (Talwani, Worzel & Landisman 1959). This structure would appear to be the result of secondary intra-crustal compressive forces and to represent the oppposite case to that of the "leaky transform fault" which reflects secondary intra-crustal extensional forces.

The various cases cited can be used to show progressive stages in the development from an incipient to a mature subduction zone (fig. 6). The asymmetry of gravity signature and inferred crustal structure of the central Macquarie Ridge Complex (along with the shallow seismicity) correspond to those of an incipient subduction system and support the predicted compressional component of relative plate motion between the Indian and Pacific plates in the region, as shown in figure 2. It is further impled that the Indian/Australian–Pacific plate boundary occurs at the Macquarie Trench where incipient westward dipping subduction of the Pacific plate is now occurring. For the northern and southern ends of the complex, gravity anomalies and inferred crustal structures (Woodward 1973) both show thickening towards the ridge. In the case of the Puysegur Trench, however, a more pronounced asymmetric root zone is defined. This, together with the occurrence of a considerably more pronounced component of underthrusting of the ocean plate in the area (Johnson & Molnar 1972), is consistent with a better developed subduction zone in that region.

Loss of around 65 km of oceanic crust of the Indian plate, due to crustal shortening, and thickening to around 150% (fig. 6) is implied by gravity results in the central Macquarie Ridge Complex north of Macquarie Island. The area is north of the zone where Weissel *et al.* (1977) interpreted crustal loss from sea-floor spreading magnetic anomaly patterns, which they considered

to be due to possible subduction or entrapment by the Pacific plate. Investigation of crustal loss in the area of the gravity profile was not possible from magnetic studies due to lack of data (J. Weissel, pers. comm.). The oceanic crust in the Macquarie Island region has probably been further thickened and shortened, compared with the location of the gravity profile, to accommodate the additional uplift of the ridge to above sea level. Crustal thickening at Macquarie Island and close to the boundary between the Indian/Australian and Pacific plates in general, is the result of transpressional forces, and is thus likely to be associated with structural features, including "flower structures", that usually occur within transpressional regimes (M. Etheridge, pers. comm.).

Uplift of some rocks of Macquarie Island by approximately 10 km during crustal thickening is indicated, since harzburgites representative of the lower ocean crust formed at depths of 5 km (Griffin & Varne 1980) have been uplifted to outcrop on Macquarie Island from water depths of around 5 km. The high dips of lavas on the island and the rotation of the south of the island relative to the central island block, by 55° clockwise around a vertical axis, which has been demonstrated from palaeomagnetic results (Williamson 1978), are also apparently associated with the transpression along the ridge crest (fig. 7). Rotation of rocks on the island is also supported from geological argument (Varne & Rubenach 1972).

The Bouguer gravity anomaly associated with Macquarie Island shows only a Bouguer gravity gradient across the island (Williamson & Rubenach 1972). This is inconsistent with local isostatic compensation of the island but consistent with deepening of the Moho towards the plate boundary at the Macquarie Trench east of Macquarie Island, as indicated by inversion of the gravity profile (fig. 6).

The characteristics of the Bouguer gravity anomalies and the inferred crustal structure over the central Macquarie Ridge Complex (fig. 6) are dissimilar to those over accreting mid-ocean ridges (e.g., for the Mid-Atlantic Ridge and the East Pacific Rise (Talwani *et al.* 1965), for the Pacific-Antarctic Ridge (Tomoda 1971), for the North Atlantic and Rykjanes Ridges (Talwani *et al.* 1971)). These typically show gravity lows which are symmetrical about the ridge axis.

SEASAT Data

SEASAT data, along with earthquake seismicity data collected over the Macquarie Ridge Complex (Ruff & Cazenave 1985), show geoid anomalies over the Hjort and Puysegur Trenches which are interpreted as being characteristic of subduction zones (fig. 8). They display the characteristic geoid signature of mature subducting trenches. This includes a narrow geoid minimum of 5–20 m amplitude and 100–400 km width directly at the trench axis. From the trench to the landward side there is a geoid high, coinciding generally with the island arc. Superimposed on this short wavelength variation is a broad positive anomaly in the geoid, with a maximum in the vicinity of the trench.

The Hjort Trench region is interpreted (Ruff & Cazenave 1985) as an oblique subduction zone

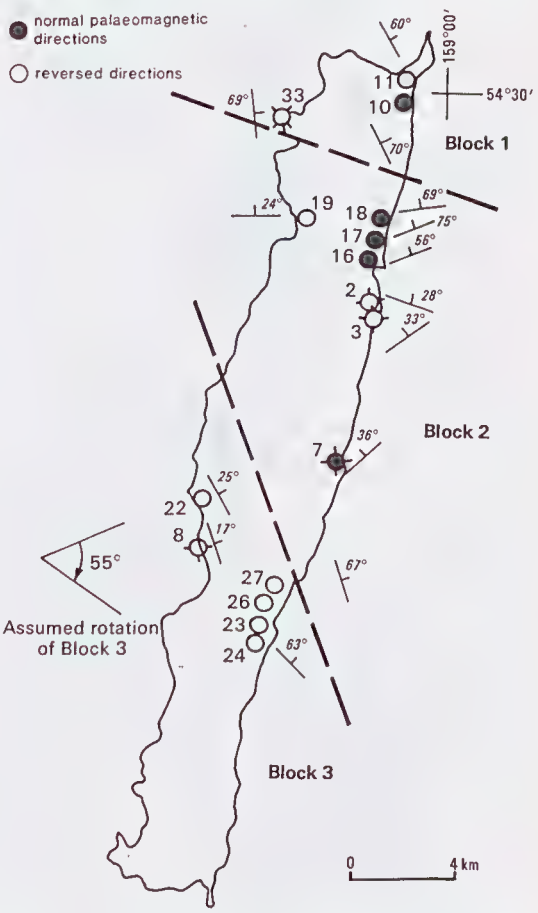


FIG. 7 — Rotation of the southern block (3) of Macquarie Island relative to the central block (2) during crustal thickening and uplift of the island, inferred from requirements for statistical compatability of apparent palaeomagnetic poles from the central and southern areas of the island. (After Williamson 1978.)

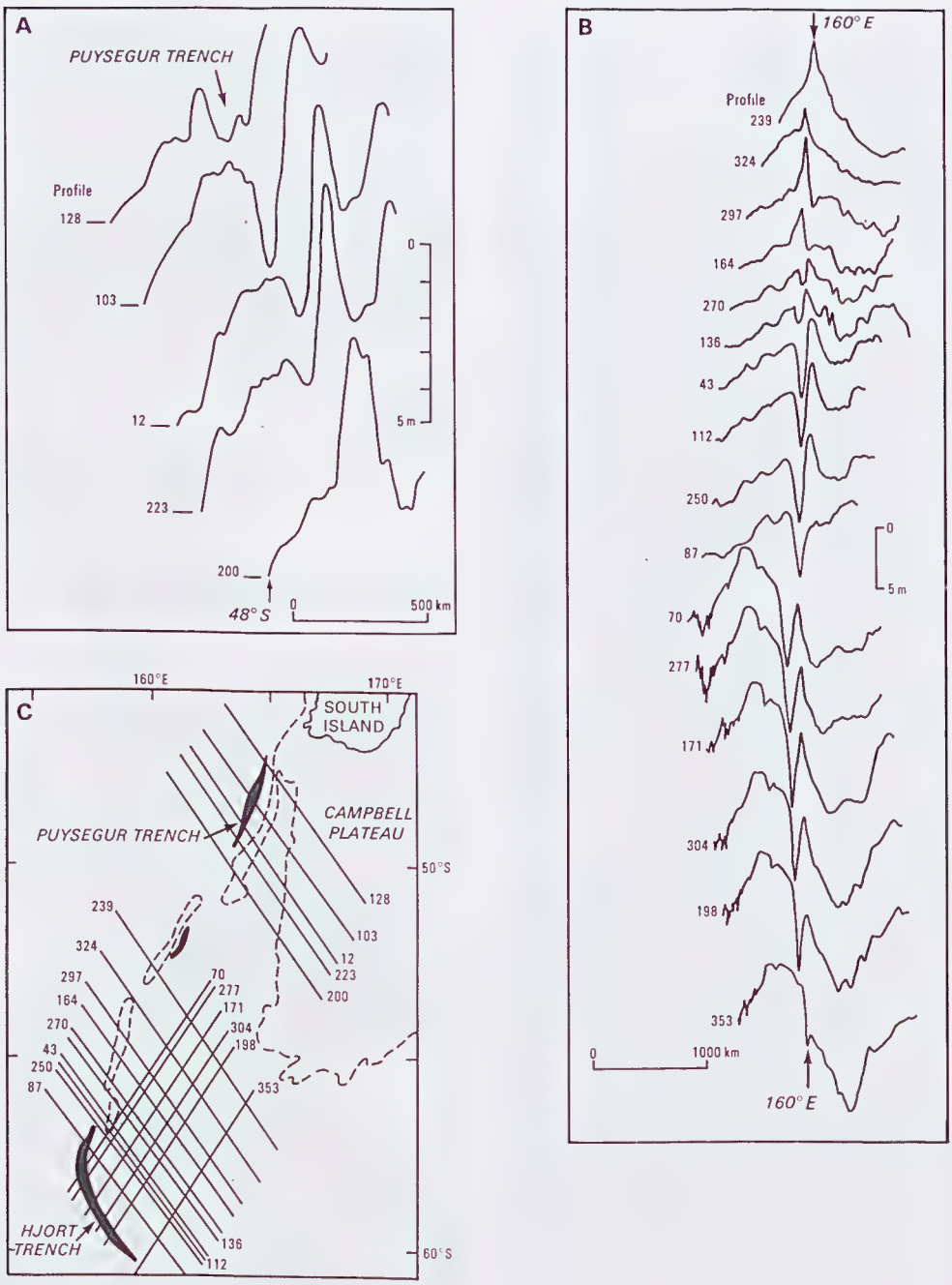


FIG. 8 — SEASAT geoid anomalies over the Macquarie Ridge Complex (A and B) and locations of profiles (C) (after Ruff & Cazenave 1985). Anomalies over the Puysegur (A) and Hjort Trenches (B; profiles 43–353) are interpreted as indicating nascent subduction. Anomalies over the Macquarie Trench (fig. B; profiles 239–136) are non-diagnostic consistent with incipient subduction.

similar to the Aleutian–Komandorski region on the basis of its geoid anomaly, while the geoid anomaly of the Puysegur Trench region is considered to be consistent with a nascent subduction zone environment. The geoid anomalies over the central Macquarie Ridge are non-diagnostic, but they are clearly not consistent with more than incipient subduction in that region; in particular, the characteristic narrow geoid minimum directly over the trench for mature subduction zones is absent.

ORIGIN OF MACQUARIE ISLAND ROCKS

Regional Pattern of Sea-Floor Spreading Magnetic Anomalies

The formation of the eastern Indian/Australian oceanic plate south of Australia, to which the Macquarie Island rocks belong, has been investigated from sea-floor spreading magnetic anomalies (Le Pichon & Heitzler 1968, Weissel & Hayes 1971, Weissel *et al.* 1977) tied to the geomagnetic time-scale of Heitzler *et al.* (1968). The magnetic anomaly lineations on the Indian/Australian plate south of the Resolution Ridge at 48°S strike eastnortheast and are interpreted as resulting from formation of Cainozoic oceanic crust at the Indian–Antarctic Ridge (fig. 9). Anomalies to anomaly 21 are identified. Anomaly lineations are offset in detail (fig. 10) by fracture zones striking northnorthwest. To the west of the Macquarie Ridge Complex north of 48°S (fig. 9), the magnetic anomalies trend in a northnorthwesterly direction and have been correlated with specific sea-floor spreading anomalies associated with the opening of the Tasman Sea (Ringis 1972, Hayes & Ringis 1973, Weissel *et al.* 1977).

An interpretation of the magnetic anomalies on the Pacific plate to the southeast of the Macquarie Ridge Complex shows the maximum age of oceanic crust in the region is about 80 Ma, anomaly 32 (78 Ma) occurring close to the Campbell Plateau (Christoffel & Falconer 1972). A sequence down to anomaly 25 occurs south of this. The next reliable identification, however, is of anomaly 5, which occurs close to the Pacific–Antarctic spreading ridge. The results imply that distinct periods of sea-floor spreading have occurred within this region, as many of the sea-floor spreading anomalies between 5 and 25 do not appear to be represented in the area (Christoffel & Falconer 1972, Adams & Christoffel 1965).

To the east of the Macquarie Ridge, at about 51.5°S and 162.5°E, anomaly lineations are poorly

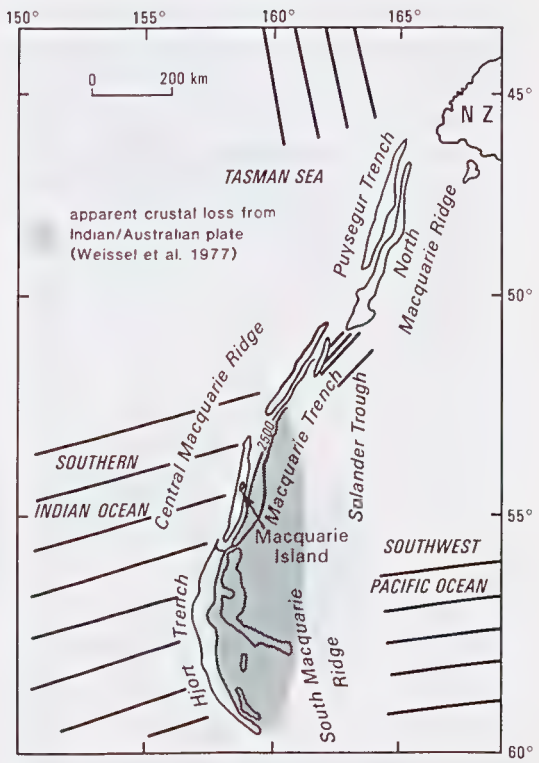


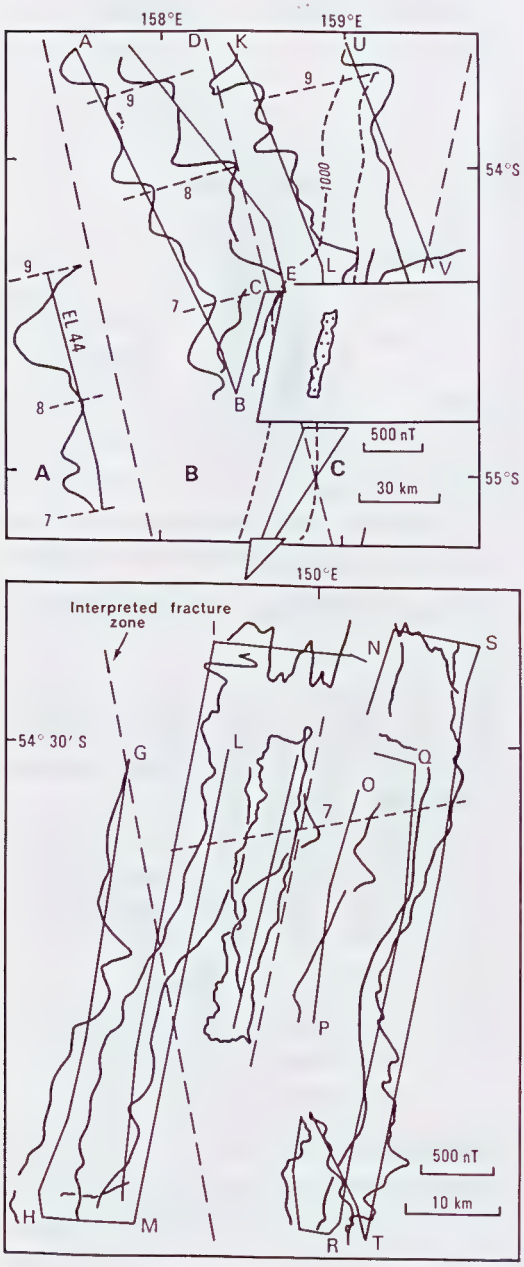
FIG. 9 — Generalised trends of marine magnetic lineations surrounding the Macquarie Ridge Complex. For the trenches 2500 fathom contours are shown.

defined but appear to trend approximately parallel to the ridge (Hayes & Talwani 1972). However, the tentative correlations may reflect structure in the sea floor rather than the normal polarity reversals. The direction of magnetic lineations has also not been established in the Emerald Basin which lies to the south of the above area. The orientation of tracks and the apparent wavelengths displayed in that area, suggest that, if lineations are present, they are probably oriented in an approximately northnortheasterly direction.

Sea-Floor Spreading Magnetic Anomalies in the Macquarie Island Region

The history of oceanic crust around Macquarie Island was investigated, using magnetic data collected along profiles parallel to the Macquarie Ridge from the *Nella Dan* (Williamson *et al.* 1981). Anomaly 7 (27 Ma) is identified, on *Nella Dan* data, to the west of Macquarie Island (fig. 10), and anomalies 8 and 9 north of the island.

These anomalies have been identified with greater confidence due to their existence as part of a longer sequence of anomalies, which extend from anomaly 7 to anomaly 21, and are observed in the *Nella Dan* data between Melbourne and Macquarie Island. The magnetic lineations parallel sea-floor spreading anomalies on the Indian/Australia plate west of the island and terminate east of Macquarie Island at the Macquarie Trench, which is interpreted to be the Indian/Australian–Pacific plate boundary; this implies that Macquarie Island occurs on the Indian/Australian plate. Offsets in the magnetic lineations suggest the presence of two minor transform faults to the west of the island. These are expressed as a deflection to the north in the magnetic lineations interpreted in the broader study of Weissel *et al.* (1977). To the west of the island, anomalies 8 and 9, observed in the Eltanin 44 data, occur about 80 km south of the same anomalies on the *Nella Dan* tracks east of a separating transform fault. A second transform fault, with a small offset, appears to trend in a northnorthwesterly direction close to the west coast of Macquarie Island. Here, anomaly 9 is interpreted to occur about 20 km to the south of the same lineations further west. Anomaly 9 is tentatively correlated over the ridge north of Macquarie Island. The shape of the anomaly is distorted, however, probably as a result of the magnetic anomaly associated with the ridge.



Sea-Floor Spreading Magnetic Anomaly Data on Macquarie Island

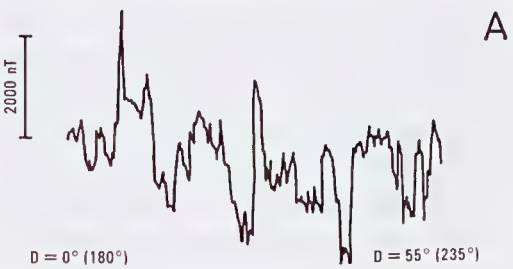
A magnetic anomaly lineation is interpreted as crossing Macquarie Island (fig. 10). The preferred identification is that it is anomaly 7 (27 Ma), since the broad features of the upwardly continued magnetic anomaly profile (to 1 km) along the island can be correlated with anomaly 7, interpreted on the adjacent marine magnetic profiles. In the onland data, the character and anomaly widths of the magnetic high and the associated low to the south are also similar to those of anomaly 7 and the associated magnetic low in the adjacent marine

FIG. 10 — Marine magnetic anomaly profiles in the vicinity of Macquarie Island to the west of the plate boundary at the Macquarie Trench. Identified anomalies are from the Heirtzler et al. *(1968) sequence. Inferred fracture zones are interpreted from offsets of the anomaly sequences. The lower part of the figure shows marine magnetic anomaly profiles close to Macquarie Island. Also shown is the main north–south profile along the island, upwardly continued to a level of 1 km, which is similar to the depths to sea floor on the marine profiles. The tentative correlation of the anomaly on either side and across the island corresponds to anomaly 7 (27 Ma B.P.).*

data. This implies the presence of remanent sea-floor spreading anomalies over, and generated by, the island lavas.

Magnetic properties of the Macquarie Island rocks, confirming the ability of the basalt lavas on the island to contribute to sea-floor spreading magnetic anomalies, have been reported by Williamson (1974, 1978), Butler & Banerjee (1973) and Butler *et al.* (1975, 1976).

Modelling of the main north–south onland magnetic profile from Macquarie Island (William-



Macquarie Island Symposium

Acknowledgement

Dr Eric Guiler not only made the initial suggestion for the Symposium but then helped to bring the Symposium to fruition as a member of the Organising Committee.

Ms Wendy Cuskelly was the Secretary of the Organising Committee and also helped in many other ways to make the Symposium a success.

P. G. Quilty D. E. Rounsevell
Honorary Organisers

Palaeomagnetic Data

Palaeomagnetic apparent pole data from Macquarie Island (Williamson 1978) have been reviewed and recalculated (paper in prep.) in relation to the revised polar wander path for the Australian plate (Idnurm 1985). No unique apparent palaeomagnetic pole for Macquarie Island is now considered possible from present data, due to the inability to resolve rotations around a vertical axis in relation to any simple structural model generated from other data. The possible range of poles in not inconsistent with inferences from marine magnetic data but cannot be said to uniquely support them.

DISCUSSION

Geophysical results can be summarised as follows:

(1) The delineation of a remanent sea-floor spreading magnetic anomaly lineation across Macquarie Island, with a trend similar to those on the Indian plate to the west, suggests that the rocks of the island were formed at the Indian/Australian–Antarctic spreading ridge.

(2) The coincidence of the trends of Indian/Australian plate sea-floor spreading lineations with the strike of dykes in the central region of the island is consistent with the model of dyke injection at a mid-ocean ridge, and further argues for the formation of the island rocks at the Indian/Australian–Antarctic spreading ridge.

(3) The interpretation of crustal structure from gravity data implies that the eastern extent of the Indian/Australian plate is at the Macquarie Trench, east of Macquarie Island, which again implies that the rocks of Macquarie Island were formed as part of the Indian/Australian oceanic plate.

(4) The preferred interpretation of the remanent magnetic lineation crossing Macquarie Island is anomaly 7 (27 Ma). This interpretation is an extension of interpretations of remanent magnetic anomalies over the oceanic crust for the Indian/Australian plate west of Macquarie Island. The interpreted age is considered to be correct within approximately +3 Ma, which corresponds to the anomaly being misinterpreted anomaly 6 or 8. Due to the structural complexity of the region such a misinterpretation may be possible. Detachment of oceanic crustal blocks at the ridge could contribute to this so that the age is more likely to be of anomaly 8 than 6, given that the motion of the Indian/Australian plate relative to the Pacific plate is dextral. That is, the age is more likely to be underestimated than overestimated. An age for Macquarie Island oceanic crust of around 10 Ma (anomaly 5) age, as suggested from recent K-Ar dating, would require either (a) that there is a spreading ridge jump of around 500 km to the north and also that the sea-floor spreading results published for the eastern Indian plate are seriously in error; or (b) that Macquarie Island crust was locally emplaced at the plate boundary; sea-floor spreading remanent anomaly trends would then parallel the Macquarie Ridge, which does not appear to be the case.

The geophysical data, with the exception of the palaeomagnetic data, are broad scale and do not relate to specific rock samples, and certainly those data argue that the rocks of Macquarie Island in general were formed at the Indian/Antarctic spreading ridge at around 27 Ma B.P.

A discrepancy exists, however, between geophysical and some palaeontological dating and all K-Ar age estimates. Palaeontological data associated with rocks from North Head ("some of the freshest volcanic rocks") on the island have given ages of middle to early Miocene (Quilty *et al.* 1973). Recent K-Ar data reported by Varne (pers. comm.), however, give young ages, normally within the last 10 Ma, for rocks of the island. Those ages essentially correspond to the normally accepted time of uplift of the ridge and island estimated from geophysical data. K-Ar ages could not be obtained for the rocks used in the palaeomagnetic study because their preservation was not considered sufficiently good for that purpose.

The apparent discrepancy between the two sets of ages could reflect two factors:

(1) essentially different data sets relating, on the one hand, to original oceanic crust and later intrusive and extrusive activity (such as seamount activity) associated with the already formed oceanic crust or, on the other, to crustal compression during formation of the Macquarie Ridge; this could result in the fresher samples being more recent, which may be particularly relevant to samples from North Head which are unusually "fresh" samples; or

(2) inaccuracies in the relatively small number of palaeontological age determinations, due to poor preservation of specimens and misidentification; loss of residual argon, due to tectonic activity during the last 10 Ma, giving young and incorrect K-Ar dates, although some of these are $^{39}Ar/^{40}Ar$ dates, which are not as susceptible to Ar loss or alteration; dating simply reflecting time of uplift; or fortuitous correlation of unrelated geophysical anomalies.

Some igneous episodes after the formation of the original oceanic crust are to be expected, however, particularly given the level of tectonic activity of the region and the nearness to the plate margin. This could suggest that factor (1) above is the dominant cause of the discrepancy. Nonetheless, it is important that investigations be carried out to resolve the discrepancy, and to this end more extensive palaeontological studies on sediments between lava layers from all areas of the island could be employed.

CONCLUSION

Macquarie Island is a rare example of uplifted oceanic crust. As such it is a geological enigma and a critical area for the study of ocean tectonics. The structure and physiographic expression of the island and the surrounding region are the result of a tectonic history of oblique compression (transpression) between the Indian/Australian and Pacific oceanic plates at their common boundary within the Macquarie Ridge Complex south of New Zealand. Intra-plate transpressive forces in this region resulted in the uplifted of oceanic crust of the Indian/Australian plate to form the Macquarie Ridge and Macquarie Island, and in incipient subduction of the Pacific oceanic plate at the Macquarie Trench. This uplift has been effected by thickening and shortening of the oceanic crust of the Indian/Australian plate, the amount of uplift being reduced by regional isostatic compensation of the increased crustal thickness. The transpressional regime has persisted during the last 10 Ma; prior to that time, strike-slip and extensional regimes occurred along the Macquarie Ridge Complex.

The uplift of Macquarie Island has been accompanied by tilting of rocks and rotation of the southern segment of the island, relative to the central segment, by about 55° in a clockwise direction around a vertical axis. In the north, gabbro and serpentinite formed at depths of up to 5 km in the primary oceanic crust, are currently exposed above sea level. Structural tilting of the island lavas has not been sufficient to reverse the primary *in situ* directions of remanent magnetisation. Consequently, long wavelength remanent magnetic sea-floor spreading anomalies associated with areas of outcropping lavas in the centre and south of Macquarie Island correlate, with the same polarity, with similar features in marine magnetic data on the Indian plate on both sides of the island. Measured magnetic properties of the island's igneous rocks confirm that their remanent magnetisations could contribute to sea-floor spreading magnetic anomalies, with the dominant contribution coming from the lava sequences and lesser contributions from gabbros and dolerites. The serpentinite samples measured do not exhibit stable NRM.

Sea-floor spreading magnetic anomaly 7 is tentatively correlated across Macquarie Island, indicating that oceanic crust, of which the island is composed, was formed at the Indian–Antarctic accreting mid-oceanic ridge around anomaly 7 time (27 Ma B.P.).

This is in conflict with evidence from younger palaeontological and K-Ar dates from the island (from Miocene to Recent) which may reflect later metamorphic or igneous episodes after the establishment of the original oceanic crust. The youngest K-Ar date, for instance, is on a metamorphic dyke from the sheeted dyke complex and reflects the timing of the closure of the metamorphic minerals as they cooled (R. Varne, pers. comm.).

To date, broad tectonic studies have presented insights into the mode of formation of Macquarie Island, the origins of its dominant rock types and the nature and result of the large-scale structural movements which affected the region. The detailed structural configurations involved are, however, poorly understood. Future work could usefully investigate the inferred presence of transpressional structures on the island, associated with the crustal thickening and uplift of deep crustal rocks, assuming sufficient data reflecting stress and strain directions can be obtained. In addition, more extensive palaeontological studies could help to resolve discrepancies in the ages of the island rocks as interpreted from existing palaeontological, K-Ar and geophysical data.

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REFERENCES

ADAMS, R.D. & CHRISTOFFEL, D.A., 1965: Total magnetic field surveys between New Zealand and the Ross Sea. *J. Geophys. Res.*, 70: 805–814.

BANGHAR, A.R. & SYKES, L.R., 1969: Focal mechanisms of earthquakes in the Indian Ocean and adjacent regions. *J. Geophys. Res.*, 74(2): 632–649.

BARAZANGI, M.W. & DORMAN, J., 1969: World seismicity maps, compiled from ESSA Coast and Geodetic Survey epicenter data, 1961–1967. *Bull. Seism. Soc. Am.*, 59(1): 369–380.

BRODIE, J.W. & DAWSON, E.W., 1965: Morphology of North Macquarie Ridge. *Nature*, 207: 844–845.

BUTLER, R.F. & BANERJEE, S.K., 1973: Magnetic properties of exposed oceanic crust on Macquarie Island. *Nature*, 244(138): 115–118.

BUTLER, R.F., BANERJEE, S.K. & STOUT, J.H., 1975: Magnetic properties of ocean pillow basalts from Macquarie Island. *Nature*, 257: 302–303.

BUTLER, R.F., BANERJEE, S.K. & STOUT, J.H., 1976: Magnetic properties of oceanic pillow basalts: evidence from Macquarie Island. *Geophys. J. R. Astro. Soc.*, 47: 179–196.

CHRISTODOULOU, C., GRIFFIN, B.J. & FODEN, J., 1984: The geology of Macquarie Island. *ANARE Res. Notes*, 21.

CHRISTOFFEL, D.A. & FALCONER, R.K.H., 1972: Marine magnetic measurements in the southwest Pacific Ocean and the identification of new tectonic features. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 197–209.

COOK, R.J.S., 1966: Some seismological features of the North Macquarie Ridge. *Nature*, 221: 953–954.

FALCONER, R.K.H., 1972: The Indian–Antarctic–Pacific triple junction. *Earth Planet. Sci. Lett.*, 17: 151–158.

GRIFFIN, B.J., 1982: Igneous and metamorphic petrology of lavas and dykes of the Macquarie Island ophiolite complex. Unpublished Ph.D. thesis, University of Tasmania.

GRIFFIN, B.J. & VARNE, R., 1980: The Macquarie Island ophiolite complex: mid-Tertiary oceanic lithosphere from a major ocean basin. *Chem. Geol.*, 30: 285–308.

HAYES, D.E. & CONOLLY, J.R., 1972: Morphology of the southeast Indian Ocean. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 125–146.

HAYES, D.E. & RINGIS, J., 1973: Sea-floor spreading in the Tasman Sea. *Nature*, 243: 454–458.

HAYES, D.E. & TALWANI, M., 1972: Geophysical investigation of the Macquarie Ridge Complex. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 211–234.

HAYES, D.E. TALWANI, M. & CHRISTOFFEL, D.E., 1972: The Macquarie Ridge. *PROCEEDINGS OF THE SCAR/IUGS SYMPOSIUM OF ANTARCTIC GEOLOGY AND SOLID EARTH GEOPHYSICS, OSLO, 1970.* Sponsored by the Scientific Committee on Antarctic Research. Universitets Forlaget, Oslo.

HEIRTZLER, J.R., DICKSON, G.O., HERRON, E.M., PITMAN, W.C. III & LE PICHON, X., 1968: Marine magnetic anomalies, geomagnetic field reversals and motions of the ocean floor and continents. *J. Geophys. Res.*, 73(6): 2119–2136.

HEISKANEN, W.A. & VENING MEINESZ, F.A., 1958: *THE EARTH AND ITS GRAVITY FIELD.* McGraw Hill Book Co., Inc.

HOUTZ, R.E. & MARKL, R.G., 1972: Seismic profiler data between Antarctica and Australia. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 147–164.

HOUTZ, R., EWING, J. & EMBLY, R., 1971: Profiler data from the Macquarie Ridge area. *In* Reid, J.L. (Ed.): *ANTARCTIC OCEANOLOGY I.* Antarctic Research Series, 15: 239–245.

IDNURM, M., 1985: Late Mesozoic and Cenozoic palaeomagnetism of Australia — I. A redetermined apparent polar wander path. *Geophys. J. R. Astr. Soc.*, 83: 399–418.

JOHNSON, T. & MOLNAR, P., 1972: Focal mechanisms and plate tectonics of the south west Pacific. *J. Geophys. Res.*, 77(26): 5000–5032.

JONES, T. & McCUE, K., 1988: The seismicity and tectonics of the Macquarie Ridge. *Pap. Proc. R. Soc. Tasm.*, 122(1): 51–57.

KIENLE, J., 1971: Gravity and magnetic measurements over Bowers Ridge and Shirshov Ridge, Bering Sea. *J. Geophys. Res.*, 76(29): 7138–7153.

LE PICHON, X. & HEIRTZLER, J.R., 1968: Magnetic anomalies in the Indian Ocean and sea-floor spreading. *J. Geophys. Res.*, 73: 2101–2117.

MAWSON, D., 1943: *Australian Antarctic Expedition Sci. Rep., 1911–1914.* Ser. A(V). Government Printing Office, Sydney, Australia.

MINSTER, J.B. & JORDAN, T.H., 1978: Present-day plate motions. *J. Geophys. Res.*, 83: 5311–5354.

MOLNAR, P., ATWATER, T., MAMMERICKX, J. & SMITH, S.M., 1975: Magnetic anomalies, bathymetry, and tectonic evolution of the South Pacific since the Late Cretaceous. *Geophys. J. R. Astron. Soc.*, 49: 383–420.

QUILTY, P.G., RUBENACH, M. & WILCOXON, J.A., 1973: Miocene ooze from Macquarie Island. *Search*, 4(5): 163–164.

RINGIS, J., 1972: The structure and history of the Tasman Sea and the southeast Australian margin. Unpublished Ph.D. thesis, University of New South Wales.

RUFF, L. & CAZENAVE, A., 1985: SEASAT geoid anomalies and the Macquarie Ridge Complex. *Phys. Earth Planet. Interiors*, 38: 59–69.

RUFF, L., GIVEN, G. & SANDERS, C., 1982: The tectonics of the Macquarie Ridge, New Zealand: new evidence of strike-slip motion from the earthquake of May 25, 1981, Mw=7.7. *EOS*, 63(18): 384.

SCHOLZ, C.H., RYNN, J.M.W., WEED, R.W. & FROHLICH, C., 1973: Detailed seismicity of the Alpine Fault Zone and Fiordland Region, New Zealand. *Geol. Soc. Amer. Bull.*, 84: 3297–3316.

SUMMERHAYES, C.P., 1969: Marine geology of the New Zealand Subantarctic sea-floor. *N.Z. Dep. Sci. Ind. Res. Bull.*, 190.

SYKES, L., 1967: Mechanism of earthquakes and nature of faulting on the mid-ocean ridges. *J. Geophys. Res.*, 72(8): 2131–2153.

SYKES, L.R., 1970: Seismicity of the Indian Ocean and a possible nascent island between Ceylon and Australia. *J. Geophys. Res.*, 75(26): 5041–5055.

TALWANI, M., HEEZEN, B.C. & WORZEL, J.L., 1961: Gravity anomalies, physiography and crustal structure of the Mid-Atlantic Ridge. *Trav. Sci. Bur. Centr. Seism. UGGI*, Int. Ser. A, fasc. 22: 81–111.

TALWANI, M. LE PICHON, X. & EWING, M., 1965: Crustal structure of mid-ocean ridges, 2. Computed model from gravity and refraction data. *J. Geophys. Res.*, 70: 341–352.

TALWANI, M., SUTTON, G.H. & WORZEL, J.R., 1959: A crustal section across the Puerto Trench. *J. Geophys. Res.*, 64: 1545–1555.

TALWANI, M., WINDISCH, C. & LANGSETH, M.G. Jr., 1971: Reykjanes ridge crest. A detailed geophysical study. *J. Geophys. Res.*, 76(2): 437–517.

TALWANI, M., WORZEL, J.L. & LANDISMAN, M., 1959: Rapid gravity computations for two-dimensional bodies with application to the Mendocino submarine fracture zone. *J. Geophys. Res.*, 64: 49–59.

TOMODA, Y., 1971: Gravity anomalies in the Pacific Ocean. Paper presented at 12th Pacific Science Congress, Canberra, Australia.

TOMODA, Y., 1973: *FREE AIR AND BOUGUER ANOMALIES IN AND AROUND JAPAN.* University of Tokyo Press.

VARNE, R., GEE, R.D. & QUILTY, P.G., 1969: Macquarie Island and the cause of oceanic linear magnetic anomalies. *Science*, 166(3902): 230–232.

VARNE, R. & RUBENACH, M.J., 1972: Macquarie Island and its relationship to oceanic crust. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 251–266.

WALCOTT, R.I., 1978: Present tectonics and Late Cenozoic evolution of New Zealand. *Geophys. J. R. Astron. Soc.*, 52: 137–164.

WATKINS, N.D. & GUNN, B.M., 1970: Petrology, geochemistry and magnetic properties of some rocks dredged from the Macquarie Ridge. *N.Z. J. Geol. Geophys.*, 14: 153–163.

WEISSEL, J.K., 1972: Analysis of marine magnetic data from south of Australia. Unpublished Ph.D. thesis, University of New South Wales.

WEISSEL, J.K. & HAYES, D.E., 1971: Asymmetric spreading south of Australia. *Nature*, 231(5304): 517–521.

WEISSEL, J.K. & HAYES, D.E., 1972: Magnetic anomalies in the southeast Indian Ocean. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 165–198.

WEISSEL, J.K., HAYES, D.E. & HERRON, E.M., 1977: Plate tectonics synthesis: the displacements between Australia, New Zealand, and Antarctica since the Late Cretaceous. *Mar. Geol.*, 25: 231–277.

WILLIAMSON, P., 1974: The structural evolution of the Macquarie Island region and its relation to ocean crust. Unpublished Ph.D. thesis, University of New South Wales.

WILLIAMSON, P., 1975: Structure of the Macquarie Ridge Complex in relation to the formation and polarity of new and fossil subduction zones. *Bull. ASEG.*, 6: 54–55.

WILLIAMSON, P., 1978: The paleomagnetism of outcropping oceanic crust on Macquarie Island. *J. Geol. Soc. Aust.*, 25: 387–394.

WILLIAMSON, P. & JOHNSON, B.D., 1974: Crustal structure of the central region of the Macquarie Ridge Complex from gravity studies. *Mar. Geophys. Res.*, II(2): 127–132.

WILLIAMSON, P. & RUBENACH, M.J., 1972: Preliminary report on geophysical studies on Macquarie Island. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19. American Geophysical Union, Washington, D.C.: 234–249.

WILLIAMSON, P., HAWKINS, L.V. & LONG, B., 1981: An examination of the possible occurrences of seafloor spreading magnetic anomalies on Macquarie Island. *Mar. Geophys. Res.*, 5: 139–155.

WOODWARD, D.J., 1973: Gravity and magnetic anomalies over the Macquarie Ridge. *In* Fraser, R. (Compiler): *OCEANOGRAPHY OF THE SOUTH PACIFIC.* N.Z. Nat. Comm. UNESCO, 1972. Wellington.

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THE AGE AND DISTRIBUTION OF THE IGNEOUS ROCKS OF MACQUARIE ISLAND

by R. A. Duncan and R. Varne

(with one table and one text-figure)

DUNCAN, R.A. & VARNE, R., 1988 (viii): The age and distribution of the igneous rocks of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 45–50. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. College of Oceanography, Oregon State University, Corvallis, Oregon, U.S.A. 973331; and Department of Geology, University of Tasmania, Hobart, Tasmania, Australia 7001.

Basalts associated with the formation of the Macquarie Ridge have been radiometrically dated at between 9.7 Ma and 11.5 Ma, giving a Middle Miocene age in approximate agreement with the age indicated by fossils in intercalated sedimentary rocks but younger than suggested by the nearby sea-floor spreading anomaly pattern. (Ed.)
Key Words: igneous rocks, radiometric analysis, tectonic uplift, Macquarie Island.

INTRODUCTION

Macquarie Island is unique among islands of the major ocean basins in being composed of oceanic crust and marks the tectonic emergence above sea level of part of the Macquarie Ridge (Varne *et al.* 1969, Varne & Rubenach 1972). The latter is a narrow arcuate welt of ridges and trenches that runs southward from New Zealand to join the Indian-Pacific mid-ocean ridge system.

The first geological map of the island was produced by L. R. Blake, a surveyor with the 1911–1914 Australasian Antarctic Expedition led by Sir Douglas Mawson. Blake was killed in the First World War, and his map was published by Mawson in his account (the first) of the geological history of the island, also based on Blake's work (Mawson 1943). This assigned the rocks of the island to an older basic group of lavas, in places intensely folded, intruded by a group of peridotites and gabbros, with both groups, following a period of erosion which exposed the intrusive rocks, overlain unconformably by a younger basic group of pillow lavas and extrusive fragmental rocks. Mawson also tentatively suggested a Cretaceous age for the formation of the rocks of the island, by analogy with the timing of tectonic and magmatic activity in New Zealand.

More recent geological mapping, including that of Varne *et al.* (1969), Varne & Rubenach (1972), Christodoulou *et al.* (1984), Crohn (1986) and Lees (1987), generally confirms the lithological distributions recorded in Blake's map, but Mawson's stratigraphic column has been questioned. Varne *et al.* (1969), who first showed that the island is formed from uplifted oceanic crust, pointed out that the older basic group described by Mawson (1943) is made up of dolerite dyke swarms and not of extrusive rocks. They also argued that the extrusive rocks of Mawson's younger basic group might be intruded by the dyke swarms, the gabbros and the serpentinised peridotites, and could therefore be the oldest rocks exposed on the island. Foraminifera from silicified oozes associated with pillow lavas were considered to be of Late Miocene or Pliocene age.

Varne & Rubenach (1972) presented new maps and geological data showing that Macquarie Island seems to be composed of a number of fault-bounded blocks, probably on all scales, derived from different layers of the oceanic lithosphere. This interpretation implies that all of the igneous rocks of the island could have been formed at much the same time, in a spreading zone in an oceanic environment, possibly the Indian–Antarctic spreading ridge. Poorly-preserved coccoliths recovered from oozes associated with North Head pillow lavas were identified by Quilty *et al.* (1973) as being of Early or Middle Miocene age.

Geochemical and geophysical data have supported the identification of Macquarie Island as uplifted oceanic crust. The basalts and dolerites are compositionally very like ocean-floor basalts from the Mid-Atlantic Ridge (Griffin & Varne 1980), and pillow lavas have magnetic properties which correspond well with those of ocean-floor basalts (Banerjee *et al.* 1974, Butler *et al.* 1976, Levi *et al.* 1978). A magnetic profile along the northern part of the island (Williamson 1974) shows a broad anomaly which has been correlated with similar anomalies in marine magnetic profiles around the island, believed by Williamson *et al.* (1981) to be

part of sea-floor spreading anomaly 7. Williamson (this volume) therefore suggests that the rocks of the island formed at the Indian-Antarctic spreading ridge at anomaly 7 time, about 27 Ma, considerably earlier than the palaeontological data suggest.

In this article, we briefly describe the geology of Macquarie Island, present a revised geological map, and provide the first radiometric determinations of the ages of Macquarie Island rocks.

THE GEOLOGY OF MACQUARIE ISLAND

The island is about 35 km long but less than 6 km wide, elongated northnorthwest along the axis of the Macquarie Ridge. It is topped by an elevated and undulating lake-studded summit plateau, best developed in the northern part of the island, which stands about 300 m above sea level and is cut off seaward by steep cliffs. A marked coastal platform with relict sea stacks occurs in places at the base of the cliffs on both sides of the island, with its greatest development at Handspike Point, where it is a kilometre wide and rises to an elevation of about 15 m above sea level (Mawson 1943).

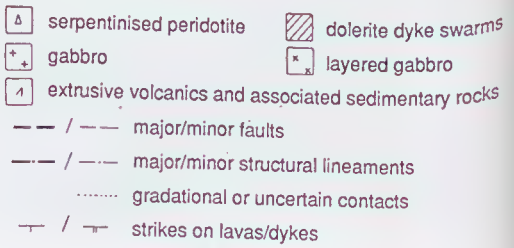
Marine, glacial and other subaerial erosional processes may have all played a part in shaping Macquarie Island from the ridge as it rose. Varne *et al.* (1969) identified raised beach deposits at 200 m on the northern summit plateau of the island, but Colhoun & Goede (1974) and Löffler & Sullivan (1980) proposed that many landforms from this part of the island are of glacial origin. Some terraces in the northern part of the island may be relicts of periglacial activity, formed at a time when cooler climatic conditions favoured the operation of solifluction processes (Löffler *et al.* 1983). Others are associated with raised beach deposits that were apparently lifted to their present position by neotectonic processes (Varne *et al.* 1969, Selkirk *et al.* 1983, Ledingham & Peterson 1984). These raised beaches are not yet dated, but deposits resting upon them are young (Selkirk *et al.* 1983). It could be that the summit plateau was largely cut by marine erosion, either before renewed compression along the Macquarie Ridge uplifted it to its present position or when sea levels were higher, in the past.

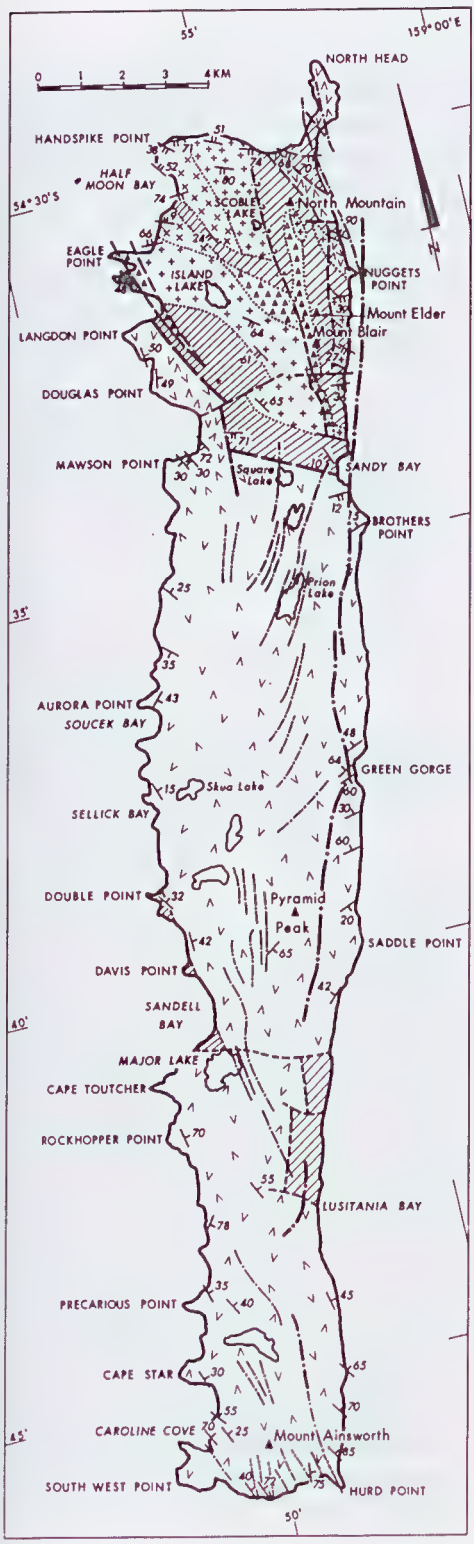
The landscape has also been modified by recent faulting. Ledingham & Peterson (1984) described recent lineaments and fault lines: some apparently displace young topographical features and are associated with topographic depressions and lakes. These young lineaments and fault lines follow generally northerly trends, subparallel to the east and west coastlines of the island and to the general trend of the Macquarie Ridge. The Brothers fault line (fig. 1) and its northern continuation are the most prominent, but less distinct, apparently older, linear features trend northwest and southwest (Ledingham & Peterson 1984, plates 6 and 7).

The northern part of Macquarie Island is formed mainly of intrusive igneous rocks, whereas the southern part is formed mainly of extrusive volcanic rocks and associated sedimentary rocks (fig. 1). The contact zone between the mainly intrusive rocks of the northern part of the island and the mainly extrusive rocks south of Bauer Bay and Sandy Bay follows a topographic depression, and corresponds in part with a northwest-trending fault zone that is marked by mylonites and flaser gabbros (Varne *et al.* 1969) and invaded by gabbroic veins, and therefore unlikely to be due to near-surface neotectonic movements. Other northwest-striking faults in the northern part of the island also appear to be older than the generally north-trending fault lines recorded by Ledingham & Peterson (1984).

The extrusive volcanic rocks are basaltic. Pillow lavas are common, and volcanic breccias, hyaloclastites, and massive lavas are also present (Mawson 1943, Varne & Rubenach 1972, Christodoulou *et al.* 1984, Crohn 1986). Thin lenses of volcaniclastic sediments, ranging from mudstone to conglomerate, tend to be associated with volcanic sequences which contain massive lavas, as at Mawson Point. Calcareous oozes occur between pillows, and are widely distributed although not abundant. Volcanic activity, therefore, occurred in a submarine setting, but the water depths at the time of deposition are unknown and may have ranged from deep to relatively shallow. Little is also known as yet of the volcanic successions or stratigraphy. An angular discordancy may occur

FIG. 1 — Interpretative geological map of Macquarie Island with superficial deposits omitted, compiled from the mapping of Varne et al. *(1969), Varne & Rubenach (1972), Griffin (1982), Christodoulou* et al. *(1984), Crohn (1986) and Lees (1987). The structural lineaments are from Ledingham & Peterson (1984).*





just east of Mawson Point (Varne & Rubenach 1972), although Lees (1987) has suggested that the variations in strike in the Mawson Point–Bauer Bay area are due to recent fault movement.

Two strike directions are commonly found in the volcanic and sedimentary rocks. South of Mawson Point and near Green Gorge, the dominant strike trends are westerly, but elsewhere they lie in the northwest quadrant. Dips range from shallow to steep, and are variable even in areas of constant strike. Narrow basaltic dykes cut the extrusive rocks. South of Brothers Point, dykes form as much as 40% of the coastal outcrop, but are generally less abundant elsewhere. The volcanic rocks may have been first tilted around axes that were near-horizontal and parallel to dyke bedding-plane intersections, causing variations in dip, and later rotated about vertical axes, causing variations in strike (Varne & Rubenach 1972, Williamson 1978).

Sheeted dyke complexes, composed of dipping series of parallel to subparallel dolerite dykes, occur mainly in the north of the island, associated with gabbros and peridotites, but are also exposed on the coasts north of Cape Toutcher and Lusitania Bay (fig. 1). Screens of gabbro, serpentinised peridotite, brecciated dolerite, and very rarely, pillow lava, have all been found within the dyke complexes, but no screens are identifiable over large areas.

Varne *et al.* (1969) reported that in the north of the island, the dykes are distributed around a near-horizontal axis trending 300°, with most dipping at about 50° to the west. They commented that the reversals in dyke dips were taken by Blake (see Mawson 1943) to be due to folding of originally-horizontal lava sheets. No systematic study has yet been made of the orientations of the dykes, of their thicknesses, or of the facings of their chilled edges. At Double Point, a transition may occur between extrusive rocks cut by many basaltic dykes into a sheeted dolerite dyke complex.

A recently-revised interpretative geological map of Macquarie Island, with superficial deposits omitted, is presented as figure 1. This map has been compiled from the mapping of Varne *et al.* (1969), Rubenach & Varne (1972), Griffin (1982), Christodoulou *et al.* (1984), Crohn (1986) and Lees (1987). In general, there is little outcrop inland on Macquarie Island, and the map is therefore more reliable along the coast. The maps of Crohn (1986) and Lees (1987), which are mainly of the northern part of the island, indicate areas where outcrop is relatively good.

South of Sandy Bay and Bauer Bay, this new

version differs little from that of Varne & Rubenach (1972), other than in the addition of the structural lineaments discovered by Ledingham & Peterson (1984). Compared with earlier maps of the northern part of the island, the main difference lies in the incorporation of a north-trending fault, northwest of Sandy Bay, mapped by Lees (1987) in its southern part. Recent east-side-up movement has occurred along this fault, which runs near-parallel to the young structural lineaments of Ledingham & Peterson (1984). In the map, this fault is sketched as continuing northwards to Hasselborough Bay, along the eastern contact of the massive gabbro, but has not yet been located by field mapping. The northnorthwest-trending faults cutting the east coast between Nuggets Point and Buckles Bay may splay off the main north-trending offshore structural lineament drawn by Ledingham & Peterson (1984) and may also be young features.

PETROLOGY AND GEOCHEMISTRY OF THE IGNEOUS ROCKS OF THE ISLAND

Gabbros and peridotites are restricted to the northern third of the island. The peridotites are serpentinised; most were originally harzburgitic assemblages of olivine, orthopyroxene and spinel (Varne & Rubenach 1972) although dunite has been found as loose blocks (Mawson 1943) and may outcrop northwest of Sandy Bay (Lees, personal communication 1987). Layered sequences of gabbroic rock are exposed at Handspike Point and along Half Moon Bay (Varne & Rubenach 1972; Crohn 1986). At Handspike Point (fig. 1), olivine gabbro is common, although troctolite and dunite are the dominant rock types (Christodoulou *et al.* 1984). Several massive gabbro bodies are exposed along the north and east coasts, and gabbro probably underlies much of the plateau (fig. 1), although exposures there are poor.

Mawson (1943), Varne & Rubenach (1972), Cameron *et al.* (1981), Griffin & Varne (1980), and Griffin (1982) have described the petrography and chemical compositions of some basalts, dolerites and gabbros. Basalts and dolerites range from coarsely porphyritic to aphyric, and from almost wholly crystalline to almost wholly glassy. Many of the extrusive rocks have been altered and metamorphosed, although fresh glass is also widespread. Where alteration is slight, crystalline groundmasses are mainly composed of clinopyroxene, plagioclase, opaques, and recrystallised glass, with pseudomorphs after olivine and rare amphibole in relatively alkaline varieties (Griffin & Varne 1980).

On North Head, Mawson Point, and in the Pyramid Peak area (fig. 1), the rocks are relatively fresh, and at worst have suffered only the smectite-carbonate alteration that is characteristic of ocean-floor weathering. Rocks from these three locations have been radiometrically dated. Elsewhere basalts were metamorphosed to higher grades, and Griffin (1982) described a section from the south of the island where the volcanic succession is about 1.4 km thick, and passes from zeolite facies assemblages through to lower greenschist facies assemblages. Intense veining and alteration is associated with fault zones (Crohn 1986). The dolerites are compositionally similar to the basalts (Griffin & Varne 1980), but tend to be more altered, displaying a widespread replacement of primary mafic minerals by actinolite. However, plagioclase survives little-changed in the dolerites, as do their doleritic textures (Varne & Rubenach 1972, Banerjee *et al.* 1974, Griffin 1982). Locally the metamorphic grade in the dolerite dykes lies within the amphibole facies.

THE RADIOMETRIC AGES OF SOME MACQUARIE ISLAND ROCKS

Seven basaltic rocks were selected from the University of Tasmania Macquarie Island collection for radiometric analyses. Results are summarised in table 1; additional analytical details are available on request. All selected samples were well crystallised and compact (rare glass and vesicles) and showed the least low-temperature alteration in the collection.

K-Ar ages were determined for four whole rock samples and one hornblende mineral concentrate from a fifth sample. The hornblende is a fresh, primary igneous phase and its age (11.5±0.3 Ma) is the time of crystallisation of its host basalt. The measured ages for the whole rock samples range from 3.6 to 9.6 Ma. Based on the petrographic evidence for low temperature formation of K-rich zeolites and clays (samples 47959, 47977 and 60635) and higher temperature metamorphism (sample 38248) these ages are minimum estimates of the true crystallisation ages. Replicate analyses of one of the samples (47977) show that the ages are reproducible and may relate to the age of alteration, from 5.8 to 9.6 Ma. The youngest measured age (3.6 Ma) comes from the stratigraphically deepest sample (38248) and may reflect the addition of K to the rock during chemical exchange with seawater.

The $^{40}Ar/^{39}Ar$ experiments were undertaken to establish more reliable crystallisation and metamorphic ages for the basaltic rocks. Three samples (60635, 47977 and 38248) were investigated

TABLE 1

K-Ar and $^{40}Ar/^{39}Ar$ radiometric ages of basaltic rocks from Macquarie Island

Sample Identification*	K-Ar ages**				$^{40}Ar/^{39}Ar$ ages**	
	% K	Radiogenic ^{40}Ar ($x10^{-11}$mol/g)	% Radiogenic Ar	Age ±1 σ (Ma)	Total Fusion Age (recombined)	Plateau Age
38248 (Nuggets Point) — dyke	0.434	0.02748	5.9	3.6±0.3	6.9±0.7	6.5±0.5
47956 (Pyramid Peak) — dyke-hornblende separate	0.389	0.80696	36.0	11.5±0.3		
47959 (Pyramid Peak) — lava flow	0.464	0.54797	7.0	6.7±1.0		
47977 (Aerial Cove) — lava flow	0.999	1.01698	7.6	5.8±0.8	9.2±0.4	9.7±0.3
		0.99950	7.6	5.7±0.8		
60635 (Mawson Point) — lava flow	0.506	0.85452	6.7	9.6±0.9	13.4±0.3	11.5±0.3
60685 (Hurd Point) — dyke					7.2±0.6***	
60820 (Souchek Bay) — lava flow					6.7±0.3***	

* University of Tasmania collection numbers.

** Ages calculated using the following decay and abundance constants: $\lambda_\epsilon = 0.581x10^{-10}$ yr^{-1}; $\lambda_\beta = 4.962x10^{-10}$ yr^{-1}; $^{40}K/K = 1.167x10^{-4}$ yr^{-1} mol/mol.

*** not recombined.

using incremental heating methods (e.g. Walker & McDougall 1982) which reveal internally consistent "plateau" ages from the argon composition released in increasing temperature steps. Total fusion ages were calculated for these samples by recombining the individual step compositions; another two samples (60685 and 60820) were analysed in a single (total fusion) experiment. Samples 60635 and 47977 are from near the top of the section and exhibit zeolite facies metamorphism to cold seawater alteration only. These show well-defined plateau ages at 11.5±0.3 and 9.7±0.3 Ma, respectively, which we interpret as original crystallisation ages. The older plateau age is identical to the K-Ar age of sample 47956 (11.5 Ma) which dates the oldest volcanic activity at Macquarie Island. The younger age dates the eruption of more alkalic flows which comprise North Head. Samples 38248, 60685 and 60820 are from the dyke swarm and lower pillow lava section and their ages reflect the end of greenschist metamorphism conditions. The age range, 6.5 to 7.2 Ma, records the time of closure of these rocks to diffusion of argon.

Griffin & Varne (1980) suggested that the coastal traverse from North Head, via Hasselborough Bay and Handspike Point to Eagle Point might represent a tilted section through ocean crust, with the extrusive rocks of North Head at the top, overlying dolerite dyke swarms and massive and layered gabbros, with serpentinised peridotites at the base. However, if volcanism at both Pyramid Peak and at North Head occurred at the Indian–Antarctic spreading ridge, this would imply a very low spreading rate of the order of 1 mm/yr.

A more reasonable interpretation is that the younger volcanism at North Head may have occurred away from the spreading axis. Off-axis seamount volcanism is observed in the Pacific Ocean (Batiza & Vanko 1984) and leads to the growth of submarine volcanoes, commonly located on or near transform faults, and ridge deflections. This would be compatible with the alkaline nature of the volcanism. Alternatively, the young north-trending lineaments and faults cutting the isthmus between North Head and Hasselborough Bay may mark the site of recent transcurrent movement along the Macquarie Ridge, throwing two diachronous sections of ocean crust against one

another. The crustal section including North Head may terminate at the zone of major faulting between Bauer Bay and Sandy Bay. This could be in part the trace of an old fracture zone separating two segments of ocean crust.

SUMMARY

Macquarie Island is made up of fault-bounded blocks of oceanic lithosphere, planated by marine erosion as they were lifted and tilted during tectonic activity associated with the formation of the Macquarie Ridge. Radiometric ages for basalts range from 11.5 Ma to 9.7 Ma, broadly compatible with the Middle Miocene ages of fossils in intercalated sedimentary rocks, but younger than the age inferred from the sea-floor spreading anomaly pattern west of the Macquarie Ridge.

REFERENCES

BANERJEE, S.K., BUTLER, R.F. & STOUT, J.H., 1974: Magnetic properties and mineralogy of exposed oceanic crust on Macquarie Island. *Zeitschr. fur Geophys.*, 40: 537–548.

BATIZA, R & VANKO, D., 1984: Petrology of young Pacific seamounts. *J. Geophys. Res.*, 89: 11235–11260.

BUTLER, R.F., BANERJEE, S.K. & STOUT, J.H., 1976: Magnetic properties of oceanic pillow basalts: evidence from Macquarie Island. *Geophys. J. R. Astr. Soc.*, 47: 179–196.

CAMERON, W.E., NISBET, E.G. & DIETRICH, V.J., 1981: Petrographic dissimilarities between ophiolitic and ocean-floor basalts. *Proc. Internat. Ophiolite Symp. Nicosia*, 1979: 182–192.

CHRISTODOULOU, C., GRIFFIN, B.J. & FODEN, J., 1984: The geology of Macquarie Island. *ANARE Res. Notes*, 21: 1–15.

COCKER, J.D., GRIFFIN, B.J. & MUEHLENBACHS, K., 1982: Oxygen and carbon isotope evidence for seawater-hydrothermal alteration of the Macquarie Island ophiolite. *Earth Plan. Sci. Lett.*, 61: 112–122.

COLHOUN, E.A. & GOEDE, A., 1974: A reconnaissance survey of the glaciation of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 108: 1–19.

CROHN, P.W., 1986: Geology and geomorphology of Macquarie Island with special emphasis on heavy metal trace element distribution. *ANARE Res. Notes*, 39: 1–28.

GRIFFIN, B.J. & VARNE, R., 1980: The Macquarie Island ophiolite complex: mid-Tertiary oceanic lithosphere from a major ocean basin. *Chem. Geol.*, 30: 285–308.

GRIFFIN, B.J., 1982: Igneous and Metamorphic Petrology of Lavas and Dykes of the Macquarie Island Ophiolite Complex. Unpublished Ph.D. thesis, University of Tasmania.

LEDINGHAM, R. & PETERSON, J.A., 1984: Raised beach deposits and the distribution of structural lineaments on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 118: 223–235.

LEES, T.R., 1987: *REPORT ON GEOLOGICAL OBSERVATIONS, MACQUARIE ISLAND, DECEMBER 1986 TO JANUARY 1987.* Antarctic Division, Kingston, Tasmania.

LEVI, S., BANERJEE, S.K., BESKE-DIEHL, S. & MOSKOWITZ, B., 1978: Limitations of ophiolite complexes as models for the magnetic layer of the oceanic lithosphere. *Geophys. Res. Lett.*, 5: 473–476.

LÖFFLER, E. & SULLIVAN, M.E., 1980: The extent of former glaciation on Macquarie Island. *Search*, 11(7–8): 246–247.

LÖFFLER, E., SULLIVAN, M.E. & GILLISON, A.N., 1983: Periglacial landforms on Macquarie Island, Subantarctic. *Zeitschr. fur Geomorph. N.F.*, 27(2): 223–236.

MAWSON, D., 1943: Macquarie Island, its geography and geology. *Australasian Antarctic Expedition Sci. Rep.*, Ser. A(5). Government Printing Office, Sydney.

QUILTY, P.G., RUBENACH, M. & WILCOXON, J.A., 1973: Miocene ooze from Macquarie Island. *Search*, 4(5): 163–164.

SELKIRK, D.R., SELKIRK, P.M. & GRIFFIN, K., 1983: Palynological evidence for Holocene environmental change and uplift on Wireless Hill, Macquarie Island. *Proc. Linn. Soc. N.S.W.*, 107: 1–17.

SELKIRK, D.R., SELKIRK, P.M. & SEPPELT, R.D., 1986: An annotated bibliography of Macquarie Island. *ANARE Res. Notes*, 38: 1–133.

VARNE, R., GEE, R.D. & QUILTY, P.G., 1969: Macquarie Island and the cause of oceanic linear magnetic anomalies. *Science*, 166: 230–232.

VARNE, R. & RUBENACH, M.J., 1972: Geology of Macquarie Island and its relationship to oceanic crust. *In* Hayes, D.E. (Ed.): *ANTARCTIC GEOLOGY II. THE AUSTRALIAN-NEW ZEALAND SECTOR. Antarct. Res. Ser.*, 19: 251–266.

WALKER, D.A. & McDOUGALL, I., 1982: $^{40}Ar/^{39}Ar$ and K-Ar dating of altered glassy volcanic rocks: the Dabi Volcanics, P.N.G. *Geochim. Cosmochim. Acta*, 46: 2818–2190.

WILLIAMSON, P., 1978: The palaeomagnetism of outcropping oceanic crust on Macquarie Island. *J. geol. Soc. Aust.*, 27(7): 387–394.

WILLIAMSON, P., HAWKINS, L.V. & LONG, B., 1981: An examination of the possible occurrences of seafloor spreading magnetic anomalies on Macquarie Island. *Mar. Geophys. Res.*, 5: 139–155.

WILLIAMSON, R., 1988: Origin, structural and tectonic history of the Macquarie Island region. *Pap. Proc. R. Soc. Tasm.*, 122(1): 27–43.

(accepted 12 April 1988)

THE SEISMICITY AND TECTONICS OF THE MACQUARIE RIDGE

by T.D. Jones and K.F. McCue

(with two tables and four text-figures)

JONES, T.D. & McCUE, K.F., 1988 (viii): The seismicity and tectonics of the Macquarie Ridge. *Pap. Proc. R. Soc. Tasm.*, 122(1): 51–57. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Australian Seismological Centre, Bureau of Mineral Resources, G.P.O. Box 378, Canberra, A.C.T., Australia 2601.

The Macquarie Ridge extends over 1200 km from southern New Zealand to a triple junction of the Pacific, Australian and Antarctic plates near 61°30′S, 161°00′E. Large earthquakes occur frequently on the ridge, with an average return period of one year for an event of magnitude 6.2 or more and 10 years for one of magnitude 7.2 or more. Analysis of 16 focal mechanism solutions indicates that the direction of the principal stress is consistently horizontal, and along the northern and central ridge segments it strikes east–west. In the southern ridge segment, its azimuth is poorly defined but appears to rotate towards the northeast with increasing southerly latitude. North of 51°S, the characteristic fault displacement is along reverse dip-slip faults, whilst south of 51°S, fault motion is predominantly by right-lateral strike-slip; throughout, the strike direction is parallel to the ridge axis.

Key Words: Macquarie Ridge, earthquakes, strike-slip, seismicity.

INTRODUCTION

The Macquarie Ridge marks the southernmost boundary between the Australian and Pacific lithospheric plates. It extends south from New Zealand to the triple junction at about 61°30′S, 161°00′E, where these two plates abut against the Antarctic plate (Falconer 1972). The ridge is a complex topographic structure (fig. 1, from Hayes & Talwani 1972) in juxtaposition with a trench system which cuts through it at about 50°S and 56°S, neatly subdividing it into northern, central and southern segments. At its northern end, the ridge is separated from the continental (?) Campbell Plateau to the east by the Solander Trough, with the Puysegur Trench extending from 46°S to 49°S to the west. The central ridge, which is narrow and flanked in the east by the Macquarie Trench, rises above sea level at 54°30′S, at Macquarie Island, and can be traced from 51°S to 56°S. The southern ridge segment is a broad feature, sloping gently eastward to the Emerald basin and separated from the Australian–Antarctic Rise in the west by the Hjort Trench which stretches from 56°S to 60°S (Hayes & Talwani 1972). Cross sections showing the varying morphology through the three ridge segments are shown in figure 2.

Associated with the Macquarie Ridge system is a narrow belt of shallow seismicity of moderately high activity (Gutenberg & Richter 1954). Epicentres of the early earthquakes were located from Australian and New Zealand data, but since 1950 a seismograph has been operated at Macquarie Island by the Australian Bureau of Mineral Resources (BMR), and the antarctic network too has slowly been extended. This improvement in the regional seismograph network has resulted in more accurate epicentral determinations and a database sufficient to compute focal mechanisms from first motion data.

SEISMICITY

We have used hypocentres from the International Seismological Centre (ISC) supplemented with data from the BMR datafile, the DSIR in Wellington, and the United States Geological Survey and its predecessors. They span the years 1960, which was the year that heralded the introduction of the Worldwide Standardised Seismographic Network (WWSSN) and the consequent dramatic improvement in precision of hypocentral parameters, up to the end of 1984. Hypocentres of earthquakes 1918 to 1959 are from Gutenberg & Richter (1954) and those from 1960 are from the International Seismological Summary (ISS).

The historical record is very scanty, with human habitation of Macquarie Island limited to occasional visits by sealers or shipwrecked mariners prior to 1948 when the Australian National Antarctic Research Expedition established a base there. Probably the earliest report is of a series of violent earthquakes commencing on 31 October 1815, with aftershock activity continuing to April

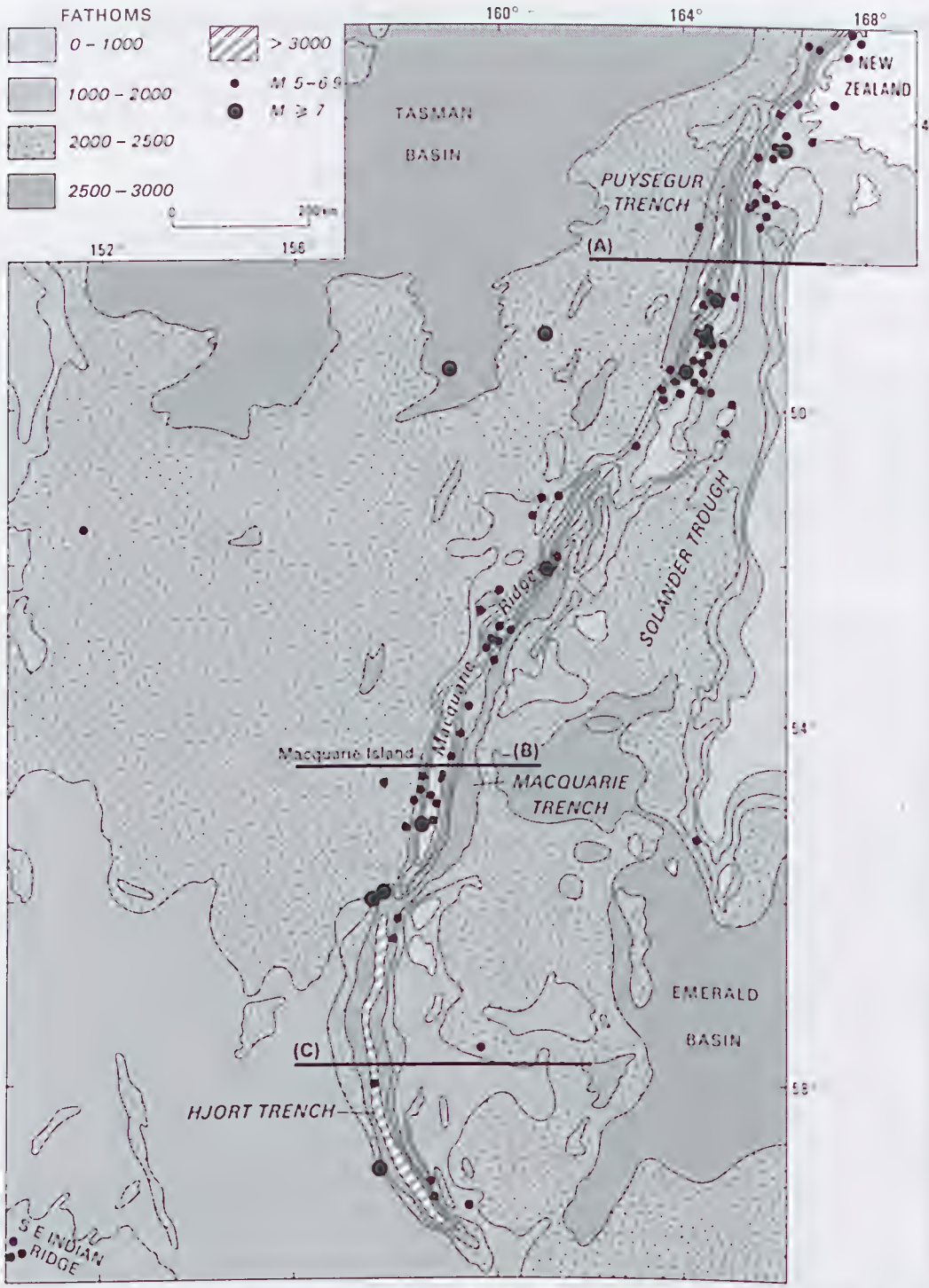


FIG. 1 — Topography and seismicity of the Macquarie Ridge. Earthquake epicentres are represented by the dots, the size indicating the magnitude.

1816 (*Sydney Gazette*, 22 June 1816). The main shock is reported to have overthrown rocks and given the ground a wave-like motion for some seconds, several men being thrown off their legs and one considerably hurt. Another sealer claimed he witnessed the fall of several mountains and the rocking of others, which seemed to have separated from the summit to the base. The precise epicentre and magnitude cannot of course be determined, but the duration of the aftershock sequence and the fact that such a long aftershock sequence was felt at all implies that the main shock had to be of magnitude 6 or above and must have occurred very close to Macquarie Island.

It is interesting to compare this with a more recent report. Extensive ground deformation was observed around the shores of Macquarie Island following the 7 February 1980 earthquake of magnitude 6.5. There were extensive rock falls and mudslides and widespread ground fractures up to 15 m long and 0.5 m deep, the largest wide enough to walk in (Ledingham 1981). Earthquakes were reported felt through to mid-October. Allowing for the difference in time and writing style between these two reports, the effects seem to be fairly similar, so the earthquakes were probably of a similar size and similarly located near the island.

Figure 1 shows epicentres for events of magnitude 5.0 or more. With few exceptions the epicentres of the post-1964 events form a single narrow band only a few tens of kilometres wide, which is within the locatable error. The focal depths are poorly constrained but, from the appearance of the seismograms, the foci appear to be very shallow and probably limited to the crust, which (according to Williamson & Johnson 1974) is less than 15 km thick under the central ridge segment. Common seismological practice was to assign a depth of 33 km, later 10 km, to earthquakes with obviously shallow but unconstrained depths, because of a lack of close seismograph stations. Both Sexton (1981) and Davies (1983) tabulated S–P times for local earthquakes recorded at Macquarie Island and found a significant number in the S–P range of 0–3 sec, corresponding to focal distances of 0 to about 20 km and indicating that at least some of the earthquakes are very shallow.

In the northern and central segments, earthquakes largely occur within the ridge rather than under the trench but this pattern is not so evident in the southern segment, where the relatively few epicentres occur beneath or near the Hjort Trench.

There is a low level of background seismicity off the ridge, commensurate with normal intraplate activity.

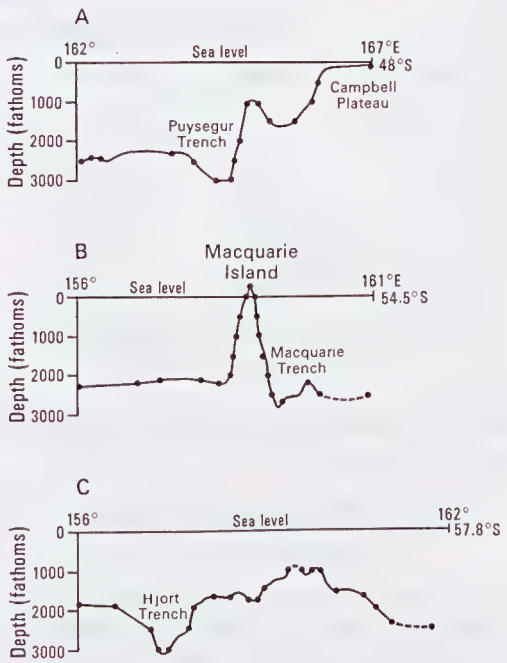


FIG. 2 — Topographic cross sections across the north, central and south segments of the Macquarie Ridge.

The greatest activity currently occurs near the southern end of the northern ridge segment. In marked contrast, immediately to the south, where the trench cuts the ridge, there has been an almost complete absence of seismicity in the past quarter-century.

The central ridge is marked by seismicity which is evenly distributed along its 500 km length, in contrast with the southern segment, where recent earthquakes are sparse but relatively large in magnitude. The lack of smaller events is not just a symptom of the poor seismographic coverage, since there were many small events in this period located farther southeast of the Hjort Trench, beyond the triple junction.

Epicentres of the 12 largest earthquakes (table 1) which have occurred along the length of the ridge since 1918 are marked by the large dots in figure 1. Some of the epicentres are more than 100 km off the ridge axis, but this distance is within the uncertainty in the epicentres and the earthquakes probably occurred along the ridge axis, though where on the ridge is impossible to determine.

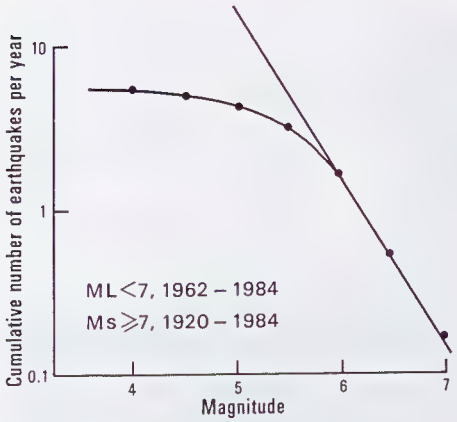


FIG. 3 — Recurrence relation for Macquarie Ridge earthquakes.

MAGNITUDE RECURRENCE RELATIONS

A plot of the cumulative frequency of earthquakes versus magnitude, for the ridge segment bounded by 47°–61°S and 155°–165°E, is shown in figure 3. The data cover the years 1962–84 for magnitudes less than Ms 7.0 and 1920–84 for magnitudes greater than or equal to Ms 7.0 (table 1). The linear portion of the plot yields a "b" value (slope) of 0.97 (±0.02). On average, the once-a-year earthquake has a magnitude of Ms 6.2, the 10-year earthquake a magnitude of Ms 7.2 and the extrapolated 100-year earthquake a magnitude of Ms 8.2. The largest earthquakes this century (table 1) occurred in 1924 and 1943 and were of magnitude Ms 7.8.

A significant feature of the recurrence relation is the relatively small number of moderate earthquakes located for the period 1962–84. We interpret this flattening of the recurrence curve to mean that some earthquakes in that period up to a Richter magnitude of 5.5 were not located; hypocentres appear in the bulletins for only half of the expected number of earthquakes of magnitude 5. This situation probably continues to the present day, due to the scarcity of sensitive seismographs in the southwest Pacific and Antarctica.

FAULT PLANE SOLUTIONS

In table 2, details are given of the 16 earthquakes for which fault plane solutions have been determined. The greatest and least principal stress axes are assumed to act at angles of 45° to the nodal planes. In addition to those already published, the

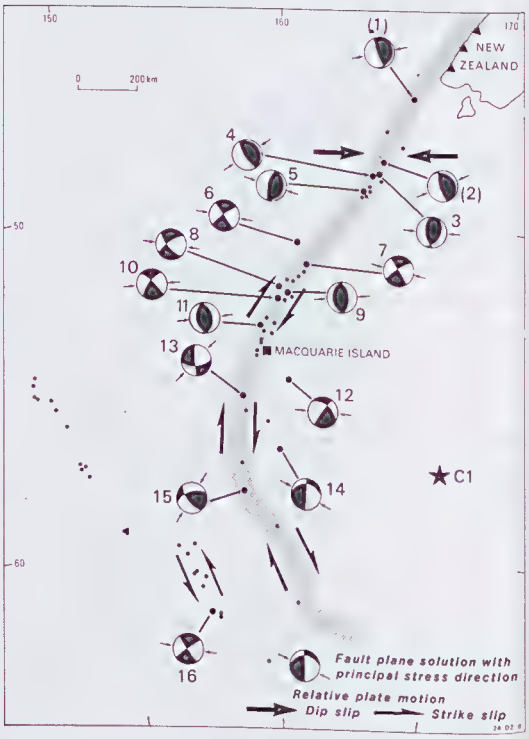


FIG. 4 — Fault plane solutions. The numbers coincide with those in table 2.

authors have drawn up an additional six fault plane solutions from the ISC bulletins for earthquakes that have occurred since the inception of the WWSSN. All events lie on the Macquarie Ridge, except for event 16 which is located on the transform fault between the Australian and Antarctic plates, near the triple junction.

The five solutions (fig. 4, events 1–5) for the northern Macquarie Ridge section include one for the Puysegur Bank earthquake of 12 October 1979, which was felt widely through the southern island of New Zealand. All five are east–west thrust mechanisms, as is that for 31 January 1985, off the southwest coast of New Zealand (*ISC Bulletin*, January 1985); the mean azimuth for the pressure axis is 257° and the mean plunge 27°. In four of the five cases, one of the nodal planes dips at a shallow angle in an approximately easterly direction, and in all five cases the complementary nodal plane dips steeply in an approximately westerly direction.

The six solutions (events 6–11) for the central ridge section have remarkably similar directions for the pressure axis, with a mean value azimuth of

TABLE 1

Major earthquakes along the Macquarie Ridge

Date			Time		Latitude	Longitude	Depth	Mag.*
y	m	d	h	m	°S	°E	km	
1924	06	26	01	37	56	157.5	33	7.8
1924	07	24	04	55	49.5	159	50	7.5
1926	10	03	19	38	49	161	50	7.5
1936	02	22	15	31	49.5	164	33	7.2
1943	09	06	03	41	55.1	158.5	0	7.8
1960	12	13	07	36	52.09	161.04	0	7.1
1964	09	12	22	07	48.95	164.46	33	(7.0)
1965	08	02	13	19	55.90	157.70	33	(7.1)
1970	06	11	16	46	58.86	157.60	33	7.2
1979	10	12	10	25	46.54	165.91	33	7.2
1981	05	25	05	25	48.55	164.70	0	7.4
1982	07	07	10	43	51.15	160.64	10	7.0

* Magnitudes are surface-wave Ms. (7.0) implies Ms computed from body-wave magnitude MB.

TABLE 2

Fault plane solutions for Macquarie Ridge earthquakes*

No.	Date			Time		Lat.	Long.	Depth	Mag.	Principal Stress Axes		Source**
	y	m	d	h	m					p axis pl/az	t axis pl/az	
1	1979	10	12	10	25	46.54	165.91	33	7.2	34/251	54/049	4
2	1981	05	25	05	25	48.55	164.70	0	7.4	27/241	62/080	1
3	1964	09	12	22	07	48.95	164.46	33	6.1MB	17/274	73/004	2
4	1964	11	08	02	43	48.98	164.20	33	5.6MB	28/236	62/056	3
5	1967	09	20	09	39	49.57	163.93	34	5.8MB	27/281	63/101	6
6	1982	07	07	10	43	51.15	160.64	10	7.0	08/101	07/193	1
7	1984	05	23	05	16	51.88	161.08	10	5.8	05/100	02/192	1
8	1969	06	17	23	58	52.53	159.70	33	6.6	27/098	02/006	1
9	1966	05	25	13	20	52.77	160.17	33	6.0MB	09/078	81/258	8
10	1979	04	23	21	54	52.93	159.84	10	6.0	05/089	20/181	1
11	1977	07	21	11	53	53.82	158.84	33	6.7	00/084	89/347	4
12	1982	06	27	16	17	55.42	160.23	10	6.2	26/271	35/161	5
13	1965	08	02	13	19	55.90	157.70	33	6.2MB	26/051	16/313	8
14	1963	05	12	09	43	57.56	159.78	33	6.4	35/116	39/240	6
15	1970	06	11	16	46	58.86	157.60	33	7.2	07/201	43/107	1
16	1983	04	27	01	39	62.50	155.30	10	5.9	07/105	01/015	7

* Magnitude is Ms (surface-wave scale) or MB (body-wave scale). Time is Universal Time, hypocentres are from the ISC or ISS.

** Focal mechanism sources are (1) Jones & McCue, this paper; (2) Sykes (1967); (3) Denham (1977); (4) Giardini *et al.* (1985); (5) Dziewonski *et al.* (1983); (6) Johnson & Molnar (1972); (7) ISC; (8) Banghar & Sykes (1969).

92° and a mean plunge of 9°. Solutions 6, 7, 8 and 10 are almost pure strike-slip, and solutions 9 and 11 are pure east–west thrust mechanisms.

Earthquake 12 occurred some 100 km east of the trench crossover which separates the central and southern ridge sections, and its mechanism is dominantly strike-slip, similar to the strike-slip mechanisms of earthquakes on the central ridge.

Earthquakes 13 and 15 seemingly occurred beneath the Hjort Trench, the axis of which rotates increasingly counterclockwise in the south. The mechanism for each contains a strong component of strike-slip motion, with one of the nodal planes striking parallel to the trench axis; the direction of the pressure axis for the more southerly event (15) is accordingly northnortheast compared to the northeast direction of the pressure axis for event 13.

Earthquake 14 occurred in the eastern part of the broad southern ridge and its fault plane solution is a combination of thrust faulting at 116°, and of strike-slip faulting. However, while the direction of thrust faulting is approximately east–west, in agreement with other thrust mechanisms along the ridge, the strike-slip component in the mechanism implies a sense of movement opposite to that of the other strike-slip mechanism, i.e. left-lateral slip along the ridge axis rather than right-lateral slip, if slip occurs along the nodal planes parallel to the ridge axis.

The focal mechanism for the earthquake of 27 April 1983 (event 16), which occurred on the Balleny Fracture Zone, resembles closely the strike-slip mechanisms of the central ridge, with a pressure axis almost east–west.

DISCUSSION

At least along the northern and central Macquarie Ridge the foci are under the ridge rather than the parallel trench. The epicentres form a single, rather narrow band until well south of Macquarie Island, where earthquakes are apparently less frequent than in the north, although the location capability decreases with distance south along the ridge.

There is some suggestion that the trench–ridge crossover points mark the places where the largest earthquakes have occurred this century, yet over the last 25 years there has been a relative lack of small and moderate earthquakes. They may be sites where either the accumulating stress is lower than in the neighbouring ridge segments because it has been released by previous large earthquakes, or where the stress level is higher but so also is the crustal strength.

Our ability to decide between the two choices is limited by the uncertainty in position of the large earthquakes earlier in the century, but the question may be clarified by an analysis of slippage rates along the ridge, which can be calculated from estimated fault dimensions of the largest recent earthquakes.

More frequent seismicity accounts for stress release along the northern and, in particular, the central Macquarie Ridge segments. The level of seismicity is lower along the southern ridge segment than the northern segments, possibly due to its position relative to the pole of rotation of the Pacific plate.

The lack of moderate or deep seismicity indicates that no well-developed subduction process exists. Perhaps the onset of subduction has only recently begun, analogous to the plate boundary along the northwest coast of the United States where there is also an absence of subcrustal seismicity. In the Fiordland region of New Zealand, there is active subduction of the Australian plate (Christoffel & van der Linden 1972); studies by the authors with P.E. Williamson, suggest that in the central Macquarie Ridge the Australian plate has been foreshortened and thickened by approximately 65 km in a process preceding subduction.

The frequency of large earthquakes is quite high, with average return periods of 1 and 10 years for earthquakes of magnitude 6.2 and 7.2 respectively. The slope of the recurrence relation "b" is 0.97 (±0.02). The decrease in "b" with decreasing magnitude suggests that some earthquakes, even up to magnitude 5.5, are not being located.

We interpret the fault plane solutions in the following way. In the northern Macquarie Ridge segment, where the trench is to the west of the ridge, the nodal plane which dips shallowly east could represent a fault plane on which subduction has recently begun in a similar sense to that off the southwest coast of New Zealand.

In the central ridge segment, thrust events have both nodal planes striking along the ridge, and either one could be the fault plane. For the strike-slip solutions, the nodal plane paralleling the ridge is probably the fault plane, in which case the sense of motion is right-lateral.

In the southern ridge segment, the fault planes also lie along the ridge axis, and so the inferred mechanisms are again strike-slip in a right-lateral sense. Hence, there is a consistent regime of right-lateral strike-slip motion, albeit with some element of east–west thrusting, along the ridge from about latitude 51°S to the triple junction.

If we choose the nodal plane parallel to the

transform fault as the fault plane for event 16, then the motion is left-lateral strike-slip, which is consistent with the motion on the transforms along the south-Indian and Pacific Ocean spreading centres.

The only inconsistent mechanism is that for event 14 and the solution has not been re-examined. This earthquake occurred in May 1963, before the completion of the World Standard seismograph network, and it is possible that few data were available to determine its mechanism.

CONCLUSIONS

From the fault plane solutions we infer that movement along the ridge is consistent with an anticlockwise rotation of the Pacific plate, relative to the Australian plate, about a pole located east of the central or south Macquarie Ridge and within some 1000 km of the ridge, as suggested by other authors (C1 in fig. 4 from Christoffel & van der Linden 1972, Minster & Jordan 1978, Johnson & Molnar 1972). Such a rotation would account for the compressive regime producing subduction in Fiordland, New Zealand, possible incipient subduction beneath the northern Macquarie Ridge, and the combination of right-lateral strike-slip and east–west thrusting observed in the central Macquarie Ridge. It is also consistent with the observed right-lateral strike-slip regime in the south Macquarie Ridge section, which continues southeast to the triple junction.

ACKNOWLEDGEMENTS

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POSTSCRIPT

On 3 September 1987, at 0640 UT, a major earthquake occurred beneath the Hjort Trench at approximately 59° 12′S, 158° 18′E. It was a shallow earthquake and the surface wave magnitude was around 7.3. The fault plane solution for this event will give additional control on the tectonic regime in the southern ridge area.

(accepted 5 January 1988)

REFERENCES

BANGHAR, A.R. & SYKES, L.R., 1969: Focal mechanisms of earthquakes in the Indian Ocean and adjacent regions. *J. Geophys. Res.*, 74(2): 632–649.

CHRISTOFFEL, D.A. & VAN DER LINDEN, W.J.M., 1972: Macquarie Ridge–New Zealand Alpine Fault transitions. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, 19: 235–242.

DAVIES, P.M., 1983: Macquarie Island Geophysical Observatory Annual Report. *Bur. Min. Resour. Rec.* 83(2): 39 pp.

DENHAM, D., 1977: *SUMMARY OF EARTHQUAKE FOCAL MECHANISMS FOR THE WESTERN PACIFIC-INDONESIAN REGION, 1929–1973.* Report SE-3, World Data Centre A for Solid Earth Geophysics: 110 pp.

DZIEWONSKI, A., FRIEDMAN, A., GIARDINI, D. & WOODHOUSE, J.H., 1983: Global seismicity of 1982: centroid-moment tensor solutions for 308 earthquakes. *Phys. Earth Planet. Inter.*, 33: 76–90.

FALCONER, R.K.H., 1972: The Indian–Antarctic–Pacific triple junction. *Earth Planet. Sci. Lett.*, 17: 151–158.

GIARDINI, D., DZIEWONSKI, A. & WOODHOUSE, J., 1985: Centroid-moment tensor solutions for 113 large earthquakes in 1977–1980. *Phys. Earth Planet. Inter.*, 40: 259–272.

GUTENBERG, B. & RICHTER, C.F., 1954. *SEISMICITY OF THE EARTH.* Princeton University Press: 310 pp.

HAYES, D.E. & TALWANI, M., 1972: Geophysical investigations of the Macquarie Ridge Complex. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN–NEW ZEALAND SECTOR.* Antarctic Research Series 19: 211–234.

INTERNATIONAL SEISMOLOGICAL CENTRE, 1961–84: *Bulletin of the International Seismological Centre*, 1(1)–21(12).

JOHNSON, T. & MOLNAR, P., 1972: Focal mechanisms and plate tectonics of the southwest Pacific. *J. Geophys. Res.*, 77(26): 5000–5032.

LEDINGHAM, R., 1981: Macquarie shakes again. *Aurora*, October 1981: 6–8.

MINSTER, J.B. & JORDAN, T.H., 1978: Present day plate motions. *J. Geophys. Res.*, 10: 5331–5334.

SEXTON, M.J., 1981: Macquarie Island Geophysical Observatory Annual Report. *Bur. Min. Resour. Rec.*, 81(17): 23 pp.

SYKES, L.R., 1967: Mechanisms of earthquakes and nature of faulting on the mid-oceanic ridges. *J. Geophys. Res.*, 72(8): 2131–2153.

WILLIAMSON, P. & JOHNSON, B.D., 1974: Crustal structure of the central region of the Macquarie Ridge complex from gravity studies. *Mar. Geophys. Res.*, 2: 127–132.

TERRACE TYPES AND VEGETATION DYNAMICS ON MACQUARIE ISLAND

by P.M. Selkirk, D.A. Adamson and R.D. Seppelt

(with two text-figures and three plates)

SELKIRK, P.M., ADAMSON, D.A. & SEPPELT, R.D., 1988 (viii): Terrace types and vegetation dynamics on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 59–64, 3 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080 4703. School of Biological Sciences, Macquarie University, New South Wales, Australia 2109; and Antarctic Division, Channel Highway, Kingston, Tasmania, Australia 7150.

Feldmark vegetation occurs extensively on the plateau of Macquarie Island above about 200 m. Alternating stripes of vegetation and gravel are frequently associated with terraced terrain. Detailed study of 38 terraced sites with non-windward aspects shows vegetation terrace interaction to be active under present climatic conditions. Wind, moisture, hillslope, slope stability and vegetation all affect terrace form.
Key Words: feldmark vegetation, terrace formation, vegetation dynamics, Macquarie Island.

INTRODUCTION

Macquarie Island is a small subantarctic island in the Southern Ocean, southeast of Tasmania, in the path of strong west to northwesterly winds. Feldmark (or fellfield or fjaeldmark) vegetation occurs extensively on the island plateau above about 200 m altitude. Amongst the 63 plant species recorded in the feldmark, bryophytes and the cushion-forming vascular plant, *Azorella selago*, are dominant. Vegetation cover is extremely variable. Large expanses of gravel-covered ground are common (Selkirk & Seppelt 1984).

Vegetation disposition ranges from regularly alternating stripes of vegetation and gravel to irregular vegetation patches amongst gravel. Regular striping may be associated with "steps and stairs" terrain. "Leeward terraces" on east-facing slopes, on which vegetation forms risers and gravel forms treads of the stairs, have been described by Taylor (1955). "Windward terraces" on west-facing slopes are less regular, with gravel risers and vegetation treads. Taylor interpreted both terrace types as responses by vegetation to the present prevailing strong westerly winds. Löffler *et al.* (1983) and Löffler (1983) regarded windward terraces as wind formed, but leeward terraces as relict solifluction landforms developed during a former, more severe climate. They described terraces on slopes with neither windward nor leeward aspects as intermediate in form.

Ashton & Gill (1965) described in detail the structure of terraces on windward slopes on North Mountain and the involvement of wind in their formation, maintenance and gradual upslope progression.

This paper concentrates on terraces on hills with other than windward aspects, following observation of a wide variety of terrace forms and dimensions; wind, moisture, hillslope, slope stability and vegetation all affect terrace form. Studies were also made of dynamic features of terraces which imply that they are not merely inherited landforms from a glacial period, but that development, stabilisation and destruction are all contemporary processes. Although terrace initiation is difficult to observe, it is believed that this could develop on unterraced hillslopes in the present environment, as, for example, following landslip.

CLIMATIC FACTORS AND FROST SORTING

Although climatic records for Macquarie Island indicate that average daily minimum, mean and maximum temperatures are all above 0°C, 51 days per year, on average, have air temperatures below zero, and 99 days per year have surface ground temperatures below zero (Löffler 1983). Ground temperatures at depths greater than 100 mm approximate air temperatures, so soil frost formation is restricted to the surface 100 mm or so (Löffler *et al.* 1983).

As meteorological data on the island are recorded at 6 m a.s.l., and temperatures are approximately 1°C lower for each 100 m increase

in altitude, occurrence of ground frost at plateau sites is likely to be significantly more frequent. Löffler (1983) estimated there would be approximately 170 days with frost at 200 m a.s.l. Precipitation averages about 900 mm per annum at the isthmus weather station, and 42% more than this at the northern end of the plateau (Mallis, this volume) so moisture for needle ice formation on the plateau is abundant.

On bare ground on the plateau, stone sorting resulting from frost action is frequently seen. Löffler *et al.* (1983) described small stone polygons on level ground, and stone stripes on ground sloping at between 2° and 20°. We have also observed frost-mediated general downslope movement of gravel, sorted so that larger stones are towards the edges and front of active chutes.

VEGETATION AND TERRACE OBSERVATIONS

Vegetation disposition in feldmark is clearly associated with hillslope, varying with increasing steepness.

No Slope

On more or less level ground, vegetation may consist of irregularly placed moss polsters and *Azorella* cushions (e.g. Boot Hill) or elongated stripes of moss, aligned at an angle of about 20° to the north of prevailing wind direction (e.g. on Windy Ridge: an unofficial name for a ridge 1 km southeast of Mt Fletcher). In some areas with slopes of less than 2° these moss stripes may be arranged in bands of alternating vegetation and bare gravel, associated with very slight terracing of the ground (e.g. Windy Ridge) (plate 1). This type of vegetation stripe has not previously been described from Macquarie Island.

Gentle Slopes

On gently sloping ground (about 0–15°) hillsides are markedly terraced approximately along the contours, with vegetated terrace risers and gravel-covered terrace treads (e.g. at Ratsak Junction: an unofficial name for the track junction on the southeast flank of Mt Martin) (plate 2 and fig. 1A). Treads may slope slightly (1–2°) either outwards or inwards, and usually slope slightly (0–5°) along their length (fig. 2). These are the leeward terraces of Taylor (1955), Löffler *et al.* (1983) and Löffler (1983).

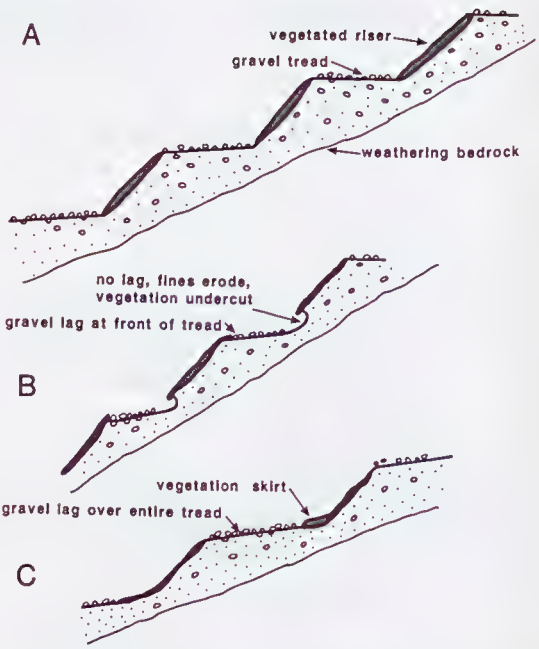

FIG. 1 — Notional sections through terraces approximately along contours. (A) Risers are vegetated, treads have gravel lag. (B) Vegetation on risers can be undercut at base when fines are eroded from a surface lacking gravel lag. (C) Vegetation extending as a "skirt" from the riser above can help stabilise the back of a tread.

Terrace vegetation dynamics yield several minor variations in the details of plant and gravel boundaries.

At the back of a tread, near the base of the vegetation of the riser above, stirring by needle ice action, followed by water washing down the riser, can gradually erode fine material away (fig. 1B). Over time, this will steepen the angle of the riser, and, as vegetation slowly grows into gravel at the front of the tread above, the riser will move upslope. The hill remains terraced but individual terraces are not fixed in their form or positions on the slope. In other cases, the back of the tread may be well stabilised by vegetation extending onto the tread from the riser above, as described below (fig. 1C).

Vegetation on the risers is predominantly *Azorella*, with *Agrostis magellanica*, *Festuca contracta*, *Acaena minor*, *Ranunculus biternatus* and a variety of bryophytes and lichens. *Rhacomitrium crispulum* and *Ditrichum strictum* sometimes form a "skirt" along the base of the riser,

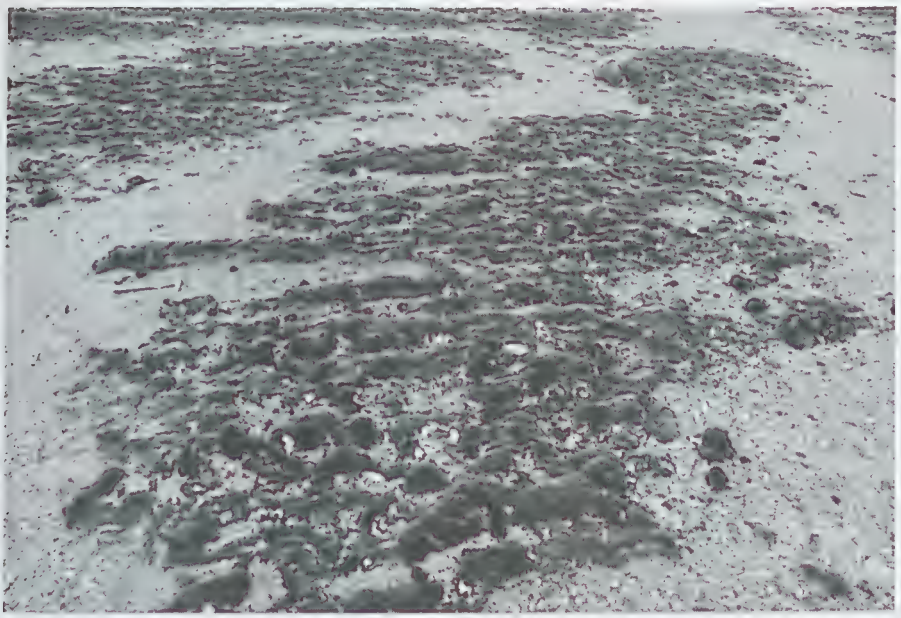

PLATE 1

Bands of moss stripes alternate with bare gravel on very slightly terraced ground on Windy Ridge, approximately 1 km southeast of Mt Fletcher. Geology hammer gives scale.

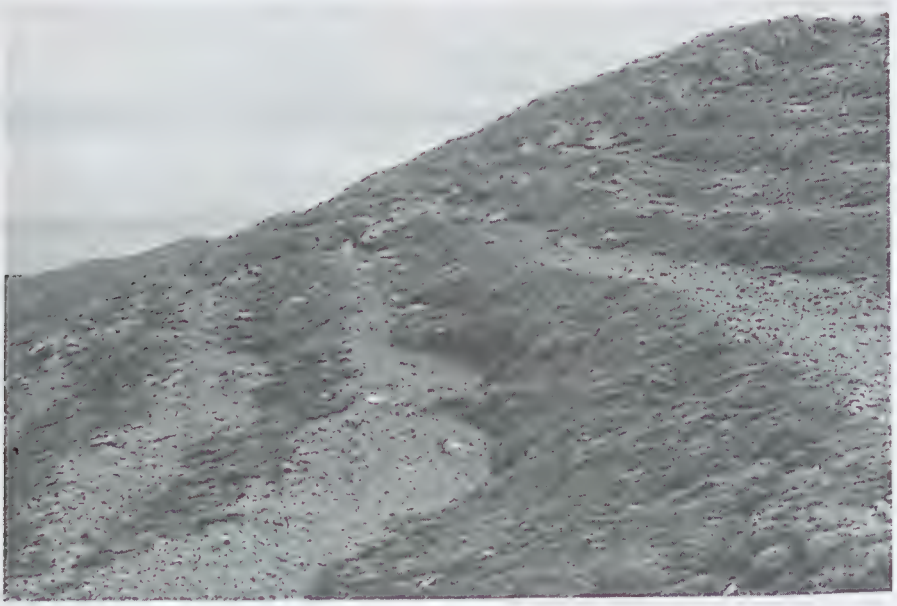

PLATE 2

Hillslope terraced approximately along contours with vegetated risers and gravel covered treads, southeast flank of Mt Martin.

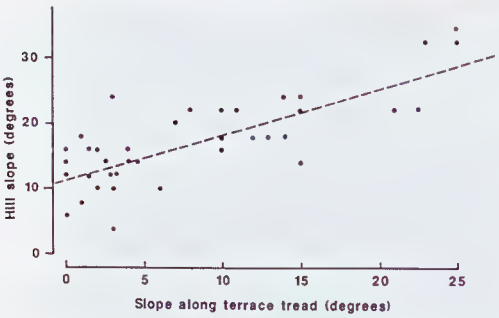

FIG. 2 — Plot of slope along terrace tread against general hillslope for 38 sites. The change from subhorizontal terrace treads to sloping treads occurs at hillslopes of approximately 11°. Regression equation: hillslope = 10.9 + 0.71 treadslope.

extending a variable distance onto the back (or inner edge) of the gravel tread. This "skirt" helps stabilise the terraces and minimise their upslope migration by protecting the back of the tread and foot of the riser from erosion.

Frost sorting of surface gravel on treads is common, with larger stones sorting to the front, or outer edge of the tread. Similar sorting occurs on the chutes which lead from one tread to the tread below. Only a few scattered polsters of *Ditrichum strictum*, *Andreaea* spp. and *Rhacomitrium crispulum* occur on treads on which frost sorting appears active. On such treads, a high proportion of fines is visible at the surface amongst the gravel. On treads where only a very small proportion of fines is visible, frost sorting of gravel appears less active, and more moss polsters, small areas of *Rhacomitrium crispulum* turf, small *Azorella selago* clumps and runners of *Ranunculus biternatus* and *Acaena minor* occur.

In a few places, completely vegetated terraces occur (e.g. southwest of Mt Martin; west of the largest of the three lakes south of Mt Blair). These completely vegetated terraces do not appear to have been described previously on Macquarie Island. The terrace tread surface becomes completely vegetated, presumably having stabilised after fines have been washed out, frost heaving has decreased, and additional supply of debris from above has been exhausted.

Measured across their surfaces at right angles to contours, treads and risers are wider on gently sloping hillsides than on slightly steeper slopes. This is often visible on a single hillside, terraced approximately parallel to its contours, where wide terraces occur low on the hill and narrower terraces higher up.

Where terrace treads are not quite parallel to contours but slope slightly along their length, the tread may itself be terraced with alternating vegetation and gravel stripes. This gives the appearance of intersecting terraces (e.g. approximately 1 km south of Mt Martin). Rarely, on much steeper slopes, completely unvegetated transverse terracing of gravel treads was observed (e.g. on the southeast flank of Mt Hamilton).

Moderately Steep Slopes

On more steeply sloping sites, both terraces and associated vegetation and gravel stripes are oriented at an increasingly steep angle to the contours. Figure 2 shows that this change from subhorizontal or gently sloping terraces occurs at a hillslope of approximately 11°. At a particular site, this threshold seems to be affected by a number of factors, including the size of gravel fragments and proportion of gravel to fines in the tread material, presence of bedrock at or near the surface to which the terrace materials become pinned, available moisture, wind exposure, altitude and hence extent of needle ice formation.

As frost action moves gravel downslope along terrace treads, larger stones are sorted to the outer edges of treads (e.g. southern shoulder of Mt Hamilton) and to the edges of chutes.

It is common to see gravel overriding vegetation at the top of risers (contrary to the observations of Löffler *et al.* 1983), to see spills of gravel across vegetation onto lower levels (plate 3), and to see chutes of gravel connecting one tread to a lower one (e.g. northeast of Mt Hamilton). Surface water flows downslope from tread to tread along such chutes, washing fine material downwards. The orientation of frost stripes on the treads, where they occur, indicates the direction of gravel movement and erosion in general.

Extremely Steep Slopes

On slopes on which gravel movement is active, vegetation occurs in patches elongated downslope, alternating with gravel stripes. Terracing is apparent at some such sites (e.g. high on the south face of Mt Hamilton).

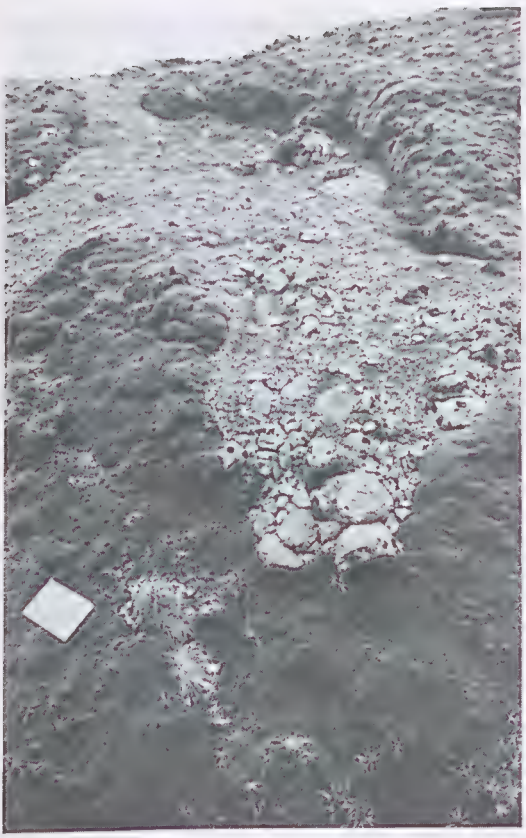

PLATE 3
Gravel commonly overrides vegetation at top of risers, spilling across vegetation onto lower levels. Notebook (150 x 90 mm) gives scale.

Other Sites

Although the terraces so far discussed have vegetated risers, terraces are not necessarily dependent on vegetation banking for either their formation or maintenance. Terracing in completely unvegetated gravel is very occasionally seen (as described at end of "Gentle Slopes" section above). At several sites (e.g. 750 m northeast of Mt Law; at the foot of the southern side of Mt Tulloch) terraces occur in short grassland. Gravel treads are well dotted with *Ditrichum strictum* polsters; the change of slope from tread to riser occurs in gravel; the upper third of the riser is devoid of vegetation, while the lower two-thirds supports short grassland vegetation (principally *Luzula crinita*, *Agrostis magellanica*, *Festuca contracta*, *Acaena minor*). This type of terrace has not previously been described on Macquarie Island.

INTERPRETATION OF TERRACES

In the Macquarie Island plateau environment there are suitable temperature and moisture conditions for needle ice formation in the top 100 mm of soil. When a mixture of fines and gravel is present, frost action causes sorting and, even on gently sloping sites, downslope movement of gravel and removal of fines from the surface leaves a surface lag of gravel. Although strong westerly to northwesterly winds are common on the island, on non-windward terraced slopes most movement of fines is downslope, washed by water from the almost constant precipitation.

At a few sites unvegetated terraces occur, but more commonly vegetation clothes the risers of terraces, stabilising them. Sorting of stones and downslope movement of gravel occur only on the treads. Gravel particles follow a zigzag path down a terraced slope, via terrace treads and interconnecting gravel chutes. Terracing lengthens the path and reduces the angle of slope down which particles travel during erosion of hillslopes.

Figure 1 and observations of the instability of the surface material imply that the mantle of mineral particles on the hillslopes is mobile and moving downslope, even if the form of the terraces may move upslope. Bedrock surfaces bear no relation to the surface profile: they may be smooth beneath strongly developed terraces. Terracing is a feature of the mobile mantle.

The nearly contour-parallel terraces resemble some forms of unsorted steps described from periglacial environments. Although Washburn (1979) described non-sorted steps as elongated downslope, Embleton & King (1975) described some forms parallel with slope contours, with vegetated risers and bare treads. Steps merge into stripes running downslope as slope increases. Embleton & King (1975) also commented that neither steps nor stripes need necessarily be associated with permafrost.

Kirkpatrick (1984) described a change from non-sorted stone steps to non-sorted stone stripes at a general slope angle of approximately 8° in some alpine areas of Tasmania. There, risers are well vegetated with herbs and shrubs to 0.5 m tall. Our observations of terraces subparallel to contours on low hillslopes and angled terraces on hillslopes steeper than approximately 11° seem analagous to Kirkpatrick's.

Observations show that terrace–vegetation interaction on Macquarie Island is active at present. Although terracing on hillslopes is likely to have been present for a considerable length of time, it is not necessary to postulate that terraces are relict features or that they required a more severe former climate for their formation.

ACKNOWLEDGEMENTS

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REFERENCES

ASHTON, D.H. & GILL, A.M., 1965: Pattern and process in a Macquarie Island feldmark. *Proc. R. Soc. Vict.*, 79: 235–245.

EMBLETON, C. & KING, C.A.M., 1975: *PERIGLACIAL GEOMORPHOLOGY*. John Wiley and Sons, New York.

KIRKPATRICK, J.B., 1984: Tasmanian high mountain vegetation II — Rocky Hill and Pyramid Mountain. *Pap. Proc. R. Soc. Tasm.*, 118: 5–20.

LOFFLER, E., 1983: Macquarie Island — eine vom Wind gepragte Naturlandschaft in der Sub-Antarktis. Polarforschung, 53(1): 59–74.

LOFFLER, E., SULLIVAN, M.E. & GILLISON, A.N., 1983: Periglacial landforms on Macquarie Island, Subantarctic. *Zeitschr. Geomorph. N.F.*, 27(2): 223–236.

MALLIS, M., 1988: A quantitative investigation into scavenging of airborne sea salt over Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 121–128.

SELKIRK, P.M. & SEPPELT, R.D., 1984: Fellfield on Macquarie Island. *Tasm. Nat.*, 78: 24–26.

TAYLOR, B.W., 1955; The flora, vegetation and soils of Macquarie Island. *ANARE Rep.*, Ser. B(II), Botany.

WASHBURN, A.L., 1979: *GEOCRYOLOGY*. Edward Arnold, London.

(accepted 2 October 1987)

LANDFORMS OF AEOLIAN, TECTONIC AND MARINE ORIGIN IN THE BAUER BAY–SANDY BAY REGION OF SUBANTARCTIC MACQUARIE ISLAND

by D.A. Adamson, P.M. Selkirk and E.A. Colhoun

(with seven text-figures and twelve plates)

ADAMSON, D.A., SELKIRK, P.M. & COLHOUN, E.A., 1988 (viii): Landforms of aeolian, tectonic and marine origin in the Bauer Bay Sandy Bay region of subantarctic Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 65–82, 12 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. School of Biological Sciences and Quaternary Research Group, Macquarie University, New South Wales, Australia 2109; and Department of Geography, University of Newcastle, New South Wales, Australia 2308.

Aeolian landforms on Macquarie Island, in the Southern Ocean, occur above 100 m on the plateau between Bauer Bay and Sandy Bay. An extensive sand sheet, at least 6000 to 7000 years old, is wind and water eroded to produce blow-outs with bare troughs and vegetated elevated margins. Sand moved eastwards before the prevailing winds. Wind-polished bedrock on the western edge of the plateau is a relict feature. Wind-polishing of bedrock occurs today near sea level at the head of Bauer Bay.

The area is tectonically active. No evidence of former glacial activity was observed. Topographic features in this area, previously regarded as glacial, are attributed to faulting.

Tectonic uplift and sea-level changes are invoked to explain the formation and age of the broad and gently sloping raised marine terrace around much of the western and northern coasts. This explanation also sets constraints on the ages of the sand sheet and the cobble beach at about 100 m on the plateau east of Bauer Bay.

Key Words: tectonic activity, fault movement, aeolian landforms, marine landforms, Macquarie Island.

INTRODUCTION

Macquarie Island (54°37′S, 158°53′E) is the highest point on the Macquarie Ridge, part of the tectonically active boundary between the Pacific and Australian plates. The plates are moving northwards at different rates with some convergence. The island is in a zone of frequent earthquakes (Jones & McCue, this volume), crustal shortening (Williamson, this volume), block faulting (Duncan & Varne, this volume), and relatively rapid uplift (Colhoun & Goede 1973, Selkirk *et al.* 1983). Macquarie Island is seamed by scores of active normal faults, many represented by youthful scarps.

At 54°S, Macquarie Island is in the path of high latitude cyclones. At the meteorological station near sea level, annual average wind speed is 8.3 ms^{-1}, annual precipitation about 900 mm, annual mean temperature 4.8°C and mean temperature for the coolest month (July) 3.3°C. Most of the island is between 100 and 300 m elevation. Snow can fall at any time but lies only briefly.

Hamilton (1926) reported that the only sand area on the island occurred on the east coast at its northern end, immediately south of the junction between the isthmus and the main island. Taylor (1955) noted the abundant sand at the head of Bauer Bay. Other areas of sand accumulation occur, particularly on the plateau on the western side of the island. The present paper describes and puts age constraints on an extensive plateau sand sheet east of Bauer Bay.

There is a long-standing and still active controversy over glaciation on the island during the last global glacial period, about 15 to 25 thousand years ago, when world sea level was some 100 to 140 m lower than today. Crohn (1986) maintains that glaciation affected most or all of the present plateau surface, whereas Ledingham & Peterson (1984) consider that many features previously ascribed to glaciation are better explained by tectonic activity, particularly as beach cobbles occur at high altitudes in supposedly glaciated areas. The present paper supports and develops Ledingham and Peterson's view that faulting is responsible for landforms previously interpreted as glacial.

A raised marine terrace (Blake *in* Mawson 1943, Colhoun & Goede 1973) extends along the northern two-thirds of the west coast of the island — a gently sloping platform rising to about 15 m

a.s.l., up to 1 km wide and mantled by peat and mire. It extends from the shoreline (tidal range about 1 m; Bye, pers. comm.) to the base of the steep slopes or cliffs which bound the plateau. Elsewhere along the coast, except in the far south-east near Hurd Point, steep slopes and cliffs rise to the high plateau directly from the ocean or from a narrow rocky shore.

This paper describes landforms in the area near Bauer Bay and Sandy Bay, where there is interplay of past and present aeolian, tectonic, fluvial and marine processes. An extensive sand-sheet, containing terrestrial peats of mid to early Holocene age and now being dissected by water and wind erosion, occurs at over 100 m a.s.l. Near sea level, present-day aeolian processes are also active. Recent faulting has affected drainage, particularly on the eastern side of the region. Finally we propose a model for the formation and age of the broad marine-cut platform on the western coast by relating it to global sea-level changes, uplift rates and dated deposits.

AEOLIAN LANDFORMS

Sand Sheet

Between Bauer Bay and Sandy Bay, a low col, at about 100 to 150 m altitude, separates higher plateau surfaces to the north from those to the south (fig. 1). On the northern side of Stony Creek is an extensive thin sand sheet (dated at least 6000 to 7000 years old from interbedded peats) which mantles the plateau surface at between 100 and 200 m altitude (figs 2 and 3). The sand extends across the col and around the flanks of Hill 236 to spill over into the head of the Finch Creek valley (fig. 4). (Note that unnamed hills are referred to by their spot heights in metres on the 1:50,000 Macquarie Island map, first edition, 1971, NMP/68/025, Division of National Mapping, Canberra, Australia.) The full extent of this sand to the east of Bauer Bay has not been traced on the ground, but it occurs north of a line from Stony Creek, across the col between Hill 210 and Hill 236 to Finch Creek. The sand deposit is dissected by wind and water erosion to form blow-outs, gullies and bare surfaces flanked by low sandy scarps (fig. 2). Layers of peat and iron-cemented sand are exposed in the scarps and on bare surfaces. Cobbles of an undated beach (Beach 5 of Ledingham & Peterson 1984) occur on the largest bare-eroded surface.

Plates 1, 2 and 3 (see figs 1 to 5 for all plate locations) show the general topography of the sandy area west of the col. Plate 1 shows the view northnorthwest across Stony Creek valley to the sand-mantled plateau and hill slope where blow-outs and gullies are visible. Plate 2 shows the view westnorthwest down the incised valley of Stony Creek with its obvious valley-in-valley form. On the northern 10° to 20° slopes of the valley, linear blow-outs (see arrow) occur with their long axes oriented roughly parallel to the contours. The 25° to 40° southern slopes are deeply gullied and free of sand. Plate shows the view from the site of the dated peat deposit (fig. 2) on the sand-mantled plateau, across the hidden, deep valley of Stony Creek to the gullies on its southern side. The general concordance of plateau surfaces north and south of Stony Creek is obvious. The distribution of sand on the plateau south of Stony Creek has not been investigated, but a cobble and sandy beach has been recorded there (Ledingham & Peterson 1984, Beach 7).

Blow-outs

Blow-outs have not been described previously from Macquarie Island. They are trough-shaped elongated hollows formed by wind eroding a pre-existing sand deposit, the sand blown from the trough accumulating downwind and to the side of the trough in a blow-out dune (Whittow 1984). Figures 2 and 3 show that the long axes of the blow-outs are parallel to the dominant and strong west to northwest winds. The slight northwards rotation of the blow-outs on the lower slopes, near Stony Creek (fig. 2, plate 2 arrow), compared with those on the plateau above, matches precisely the orientation of the valley and is accounted for by winds channelled up the valley. Small blow-outs on the eastern edge of figure 2 show slight but definite divergence due to wind flow around a ridge.

Figure 3 shows several blow-outs on a 10° south-facing slope, mantled by sand and dissected by drainage lines. Cross-sections (AF, GL) of the blow-out in the centre of the diagram show the convex shape of the sandy body (BE, HK), inset into which is a trough V-shaped in plan view with an east-pointing apex. Its sandy floor (CD, IJ) is flanked to north and south by steep edges. At the eastern end of the blow-out (east of IJ) the sandy trough changes to a sandy tongue roughly coincident with the dune surface. Plate 4 shows the sandy trough in the foreground, widening westwards. In Plate 5, a person stands where the deeply inset trough, sloping westwards behind the person, changes into an eastward-sloping sandy tongue roughly level with the surface of the convex blow-out dune.

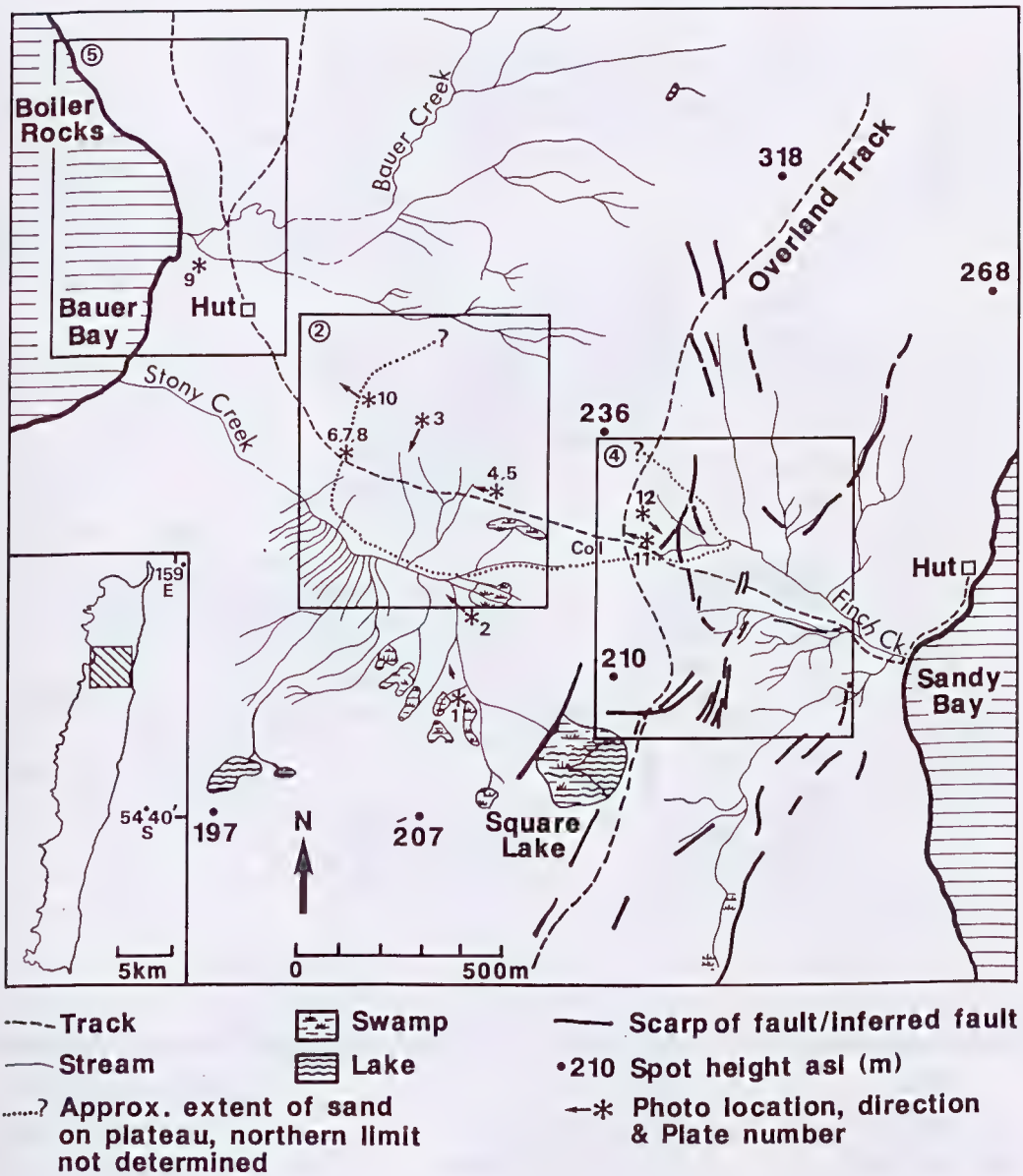


Fig. 1 — The Bauer Bay–Sandy Bay region of Macquarie Island showing the location of larger scale maps (figs 2, 4 and 5). Information for the maps was derived from: 1:50,000 map Australia, Macquarie Island, first edition, November 1971, Division of National Mapping, Canberra; from 1976 air photos; and from field work. The drainage pattern differs substantially from that shown on the published 1:50,000 map.

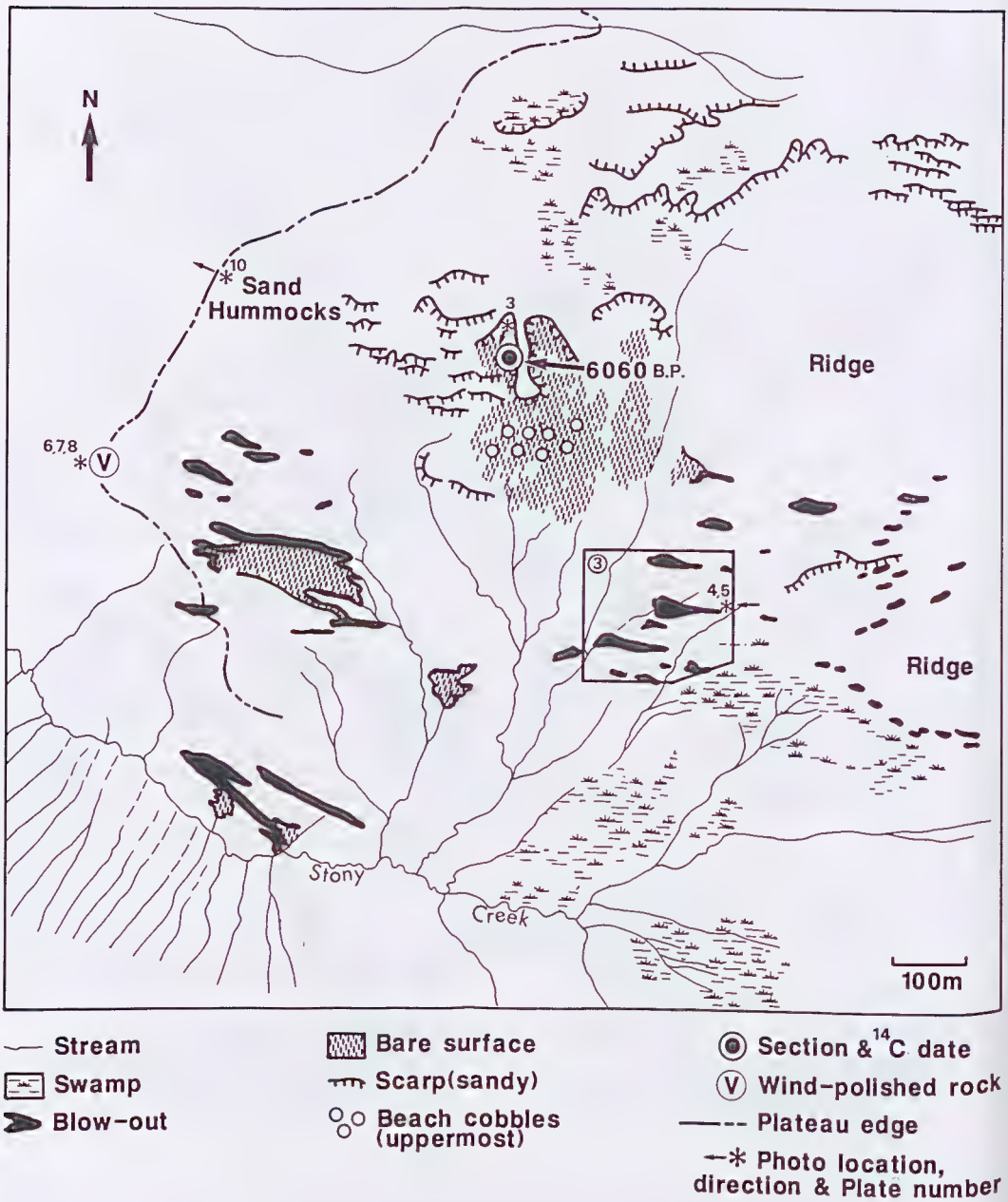


Fig. 2 — Part of the sand sheet on the plateau north of Stony Creek. Location of figure 3 is shown. The dated terrestrial peat (Beta 20167: 6060 ± 70 B. P.) occurred as a basal band 30 mm thick, 2.78 m below the surface of the sand sheet and overlying angular cobbles and weathered bedrock.

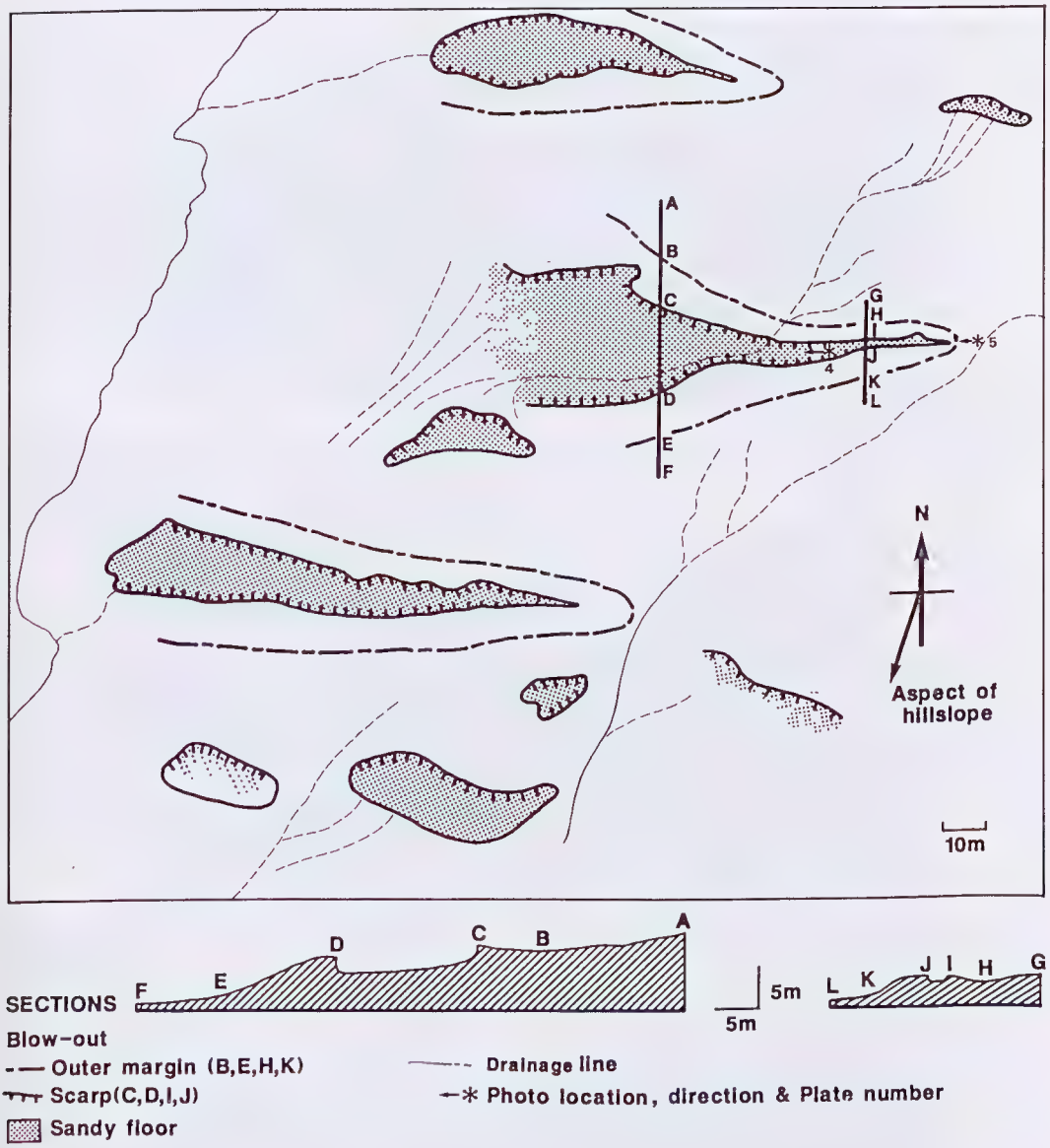


Fig. 3 — Detailed plan and sections of blow-outs on the sand sheet at about 100 m altitude on the plateau north of Stony Creek.

Starting from the wide western end, the sandy floor of the blow-out slopes very gently up towards the east, but as the V narrows the slope steepens slightly to reach a broad crest (close to the position of IJ in fig. 3 and the person in plate 5). To the east of this crest the slope falls gently towards the tip of the bare sandy tongue (plate 5) at the eastern end of the blow-out dune. The dominant and severe westerly winds accelerating into the funnel of the V-shaped trough presumably pick up sand from the gently rising western two-thirds of the trough and drop it to the east of the crest on the gentle downslope. The rising western (windward) side of the longitudinal trough is a wind erosion zone but the eastern (lee) slope is a depositional zone. So long as the sand supply is adequate, and while water erosion does not carry too much sand downhill, the blow-out trough and dune move slowly downwind towards the east, the trough progressively eating into, and blowing forward, its own dune.

The blow-outs are oriented approximately across the hillslope and, because of their convex transverse profile, pond or divert drainage (fig. 3, B and H). Ponding on the upslope side of blow-outs results in seepage of water into their troughs. Between transects AF and GL, a drainage line has broken through the blow-out dune, so that the trough westwards has become a minor creek. The floors of blow-outs also intercept subsurface water moving downslope along relatively impervious surfaces of weathered bedrock, buried peat or layers of iron-cemented sand. Consequently the floors and sides of troughs are often saturated with water, as shown in plate 4 and in plate 5 beyond the person. Water flow and seepage probably contribute to the development of blow-outs by transporting sand from the steeper sides and slopes of the trough to the gentler slopes of the floor. Borowka (1980) found that wind around 15 to 20 ms^{-1}, even for brief periods, is effective at moving sand from wet, cold (2°–6° C) surfaces, and that changes in air viscosity and density at low temperatures increase the effectiveness of cold air in moving sand. Conditions described by Borowka are similar to those on Macquarie Island. Jungerius *et al.* (1981) also noted that rain had little effect on wind erosion in blow-outs in Holland, possibly because strong winds desiccate the surface of wet sand quickly so that the effect of precipitation is short-lived.

The flanks of the blow-out are well vegetated. Only the incised trough (CD, IJ) and the narrow sandy tongue east of IJ are bare or sparsely vegetated (plates 4 and 5). Sparse colonisation is visible in the background in plate 4, at the broad western part of the trough where the sand supply has been depleted. Plate 5 shows a narrow rim of *Acaena magellanica* adjacent to the bare sand, its stolons growing onto the sandy surface. *Luzula crinita* and *Pleurophyllum hookeri* occur with *Acaena magellanica* to form a complete cover of vegetation over the rest of the blow-out dune. The vegetated eastern end of the blow-out (the deposition zone) traps sand and builds up its convex surface as fast as sand is blown from the west (the erosional zone), plant growth roughly keeping pace with sand supply. The eastern advancing tip of the dune is about 500 mm above the adjacent surface. Build-up and advance of the blow-out dune will cease when sand supply declines. In the wet environment of the island, plant growth is rapid, so that no leeward slip-slope of bare sand develops, as might occur in drier, warmer environments. Once the sand grains are blown from the trough of the

PLATE 1

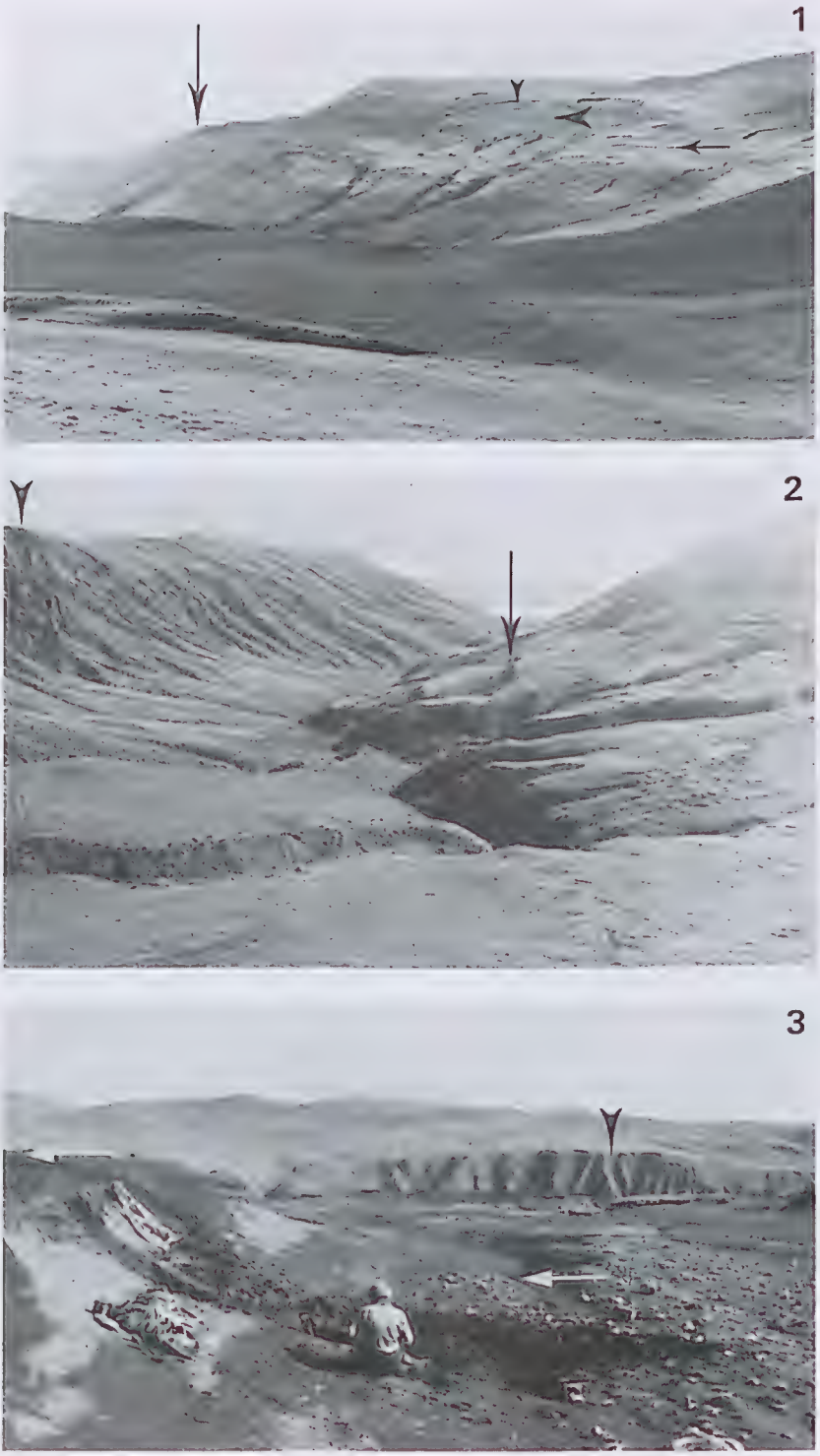
Stony Creek valley looking northnorthwest to the sand-mantled plateau and hill slope (much of which is shown in fig. 2). Part of the marine terrace north of Bauer Bay is visible on the coast. The beach marked by rounded cobbles (Beach 5 of Ledingham & Peterson 1984) is shown by the large horizontal arrowhead; the eastern edge of the blow-outs mapped in figures 2 and 3, by the small horizontal arrow; the location of the dated peat (Beta 20167: 6060 $^{-1}$ 70 B.P.) near the base of the sand sheet, by the small vertical arrowhead; the wind-polished bedrock (fig. 2 and plates 6, 7 and 8), by the large vertical arrow. Locations of all plates are shown on the relevant figures.

PLATE 2

Stony Creek valley looking westnorthwest. Linear blow-outs occur on the northern (right-hand) slope, one at low level is marked by the vertical arrow. The arrowhead marks the crest of the steep southern slope, also marked on plate 3.

PLATE 3

Looking southwards across the deeply incised valley of Stony Creek, most of which is hidden. The arrowhead shows the same location marked in plate 2. The surface and base of the sand sheet is marked by two horizontal white arrows. Dated peat (Beta 20167: 6060 $^{-1}$ 70 B.P.) was excavated at this site from the base of the sand sheet. Beneath the sand sheet is a strew of angular cobbles and weathered bedrock.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erosional zone, they are trapped where they fall by the vegetation in the accumulation zone. At the leeward (eastern) end of the blow-out, instead of a slip-slope of bare sand, there is a broad convex apron or lobe of accreting vegetated sand.

Deepening of the trough of the blow-out is limited by the depth of poorly consolidated sand. When a resistant surface of any sort is reached, the trough widens rather than deepens. Wind acceleration is less than it would be in a narrow trough, water erosion becomes relatively more important than wind erosion, and the possibility of plant colonisation of the now more stable surface increases (plate 4, background). By this stage, the most active part of the blow-out is further east. Several blow-outs may coalesce. A bare area in figure 2 (about 300 m west of the location of fig. 3) probably represents such an area, with much of the sand washed down towards Stony Creek. Near the cobble beach, the broad area bare of vegetation, bounded by sandy scarps, probably resulted from a long period of aeolian reworking of the sand deposit and sand removal by sheet and gully erosion.

Bedrock Polished and Grooved by Wind

Colhoun & Goede (1974) first recorded wind-polished and grooved rocks at the plateau margin above Bauer Bay. These bedrock exposures occur at about 100 m a.s.l. beside the Bauer Bay–Sandy Bay walking track, a few metres below the ridge/plateau crest at the top of the steep climb out of Bauer Bay, about 500 m southeast of the hut (figs 1 and 2). The polished surfaces of these rocks are fully exposed to the prevailing west to west-northwest wind. Plates 6, 7 and 8 show that wind-driven sand is not active at the site today, nor was it in the recent past, because ventifacted surfaces are colonised by large lichen colonies up to 250 mm in diameter and by moss clumps which encroach on the polished surfaces for over 100 mm (plate 8). The linear wind-eroded grooves are 40 to 120 mm in length, up to 25 mm wide and about 10 mm deep (plate 7) attesting to the severe erosive effect of blown sand. Similar erosional marks in the form of elongated pits on wind-polished rock are common in polar sandy deserts of Antarctica (Selby 1977, Pickard 1982, Adamson & Pickard 1986). The linear grooves visible in plates 6 and 7 are oriented at 310°, parallel to the present prevailing wind, leading to the conclusion that the dominant wind direction has not altered since their formation.

Wind-polished rock also occurs a couple of metres above sea level, about 100 m inland from the present high tide limit, on the sandy plain in Bauer Bay (plates 9 and 10, figs 1 and 5). This contemporary polish is less well developed than on the fine-grained rock at high altitude, because the rock near sea level is coarse-grained and may have been exposed to wind for a relatively short time. Ventifact formation on this sand plain confirms the ability of strong winds to move sand from normally wet surfaces in the moist cold environment of Macquarie Island and illustrates one situation in which wind-polish by blown sand can occur.

Sand Hummocks

Mounds of sand up to 1 m tall, covered by dense *Acaena magellanica*, form a hummocky landscape below bare slopes in the headwaters of Finch Creek (plate 11, fig. 4). Hummocks vegetated by *Poa foliosa* occur near the plateau edge overlooking Bauer Bay (fig. 2). In the case of hummocks covered by *Acaena*, the plant's ability to trap sand blown from adjacent unvegetated surfaces accounts for hummock growth. Juxtaposition of bare erosional and depositional surfaces is particularly clear near the intersection of the Overland and Bauer Bay–Sandy Bay tracks (fig. 4). Sand moved across the plateau from the west cascades eastwards down 15° slopes into the upper valley of Finch Creek (plates 11 and 12). Mobile sand is either washed into the upper tributaries or blown into, and trapped by, the dense vegetation.

Radiocarbon dated peat (Beta 20159: 5680 ± 80 B.P. or 6575 ± 225 B.P. when calibrated following Klein *et al.* (1982), from 6.52 m below the base of the modern vegetation, see arrow in plate 12 and fig. 4) at the base of the hummocky sand sheet shows that sand transgressed the site at least 6500 years ago. Since then sand has been supplied to and stripped from the slope by wind and water erosion, with periods of stability as shown by a date of 3230 ± 90 B.P. on peat at a depth of 3.88 to 3.91 m (Beta 20160). At present the site is being eroded by water and wind, revealing the stratigraphy of the interbedded peats and sands.

Residual sand hummocks also occur on the sandy plain near sea level in Bauer Bay (fig. 5) and on the plateau where sandy scarps mark remnants of a formerly more complete surface (fig. 2).

On the plateau edge above Bauer Bay, and draped for a short distance down the steep slope below, is a sand deposit with a form reminiscent of a climbing dune. Alternatively, it may be a relic of a more extensive mantle of sand on the steep seaward slopes leading up to the plateau. This dune-like feature is adjacent to an area of hummocky sand

PLATE 4

Blow-out. The person is near location D in figure 3. Free water on the sandy surface of the trough within the blow-out is shining. Sparse revegetation is visible in the wide western part of the trough in the middle distance. The vegetation most clearly visible is Pleurophyllum hookerii *(white arrow) and* Acaena magellanica *(black arrow).*

PLATE 5

Blow-out viewed from beyond its eastern end, looking westwards. The person is a few metres west of IJ in figure 3. The approximate positions of H and K in figure 3 are shown by broad white arrows. The small arrowhead points to Acaena magellanica *colonising bare sand, the large arrowhead to mixed* Luzula crinita *and* Acaena, *and the small white arrow to* Pleurophyllum hookeri. *The curved white arrow indicates the eastern advancing tip of the blow-out.*

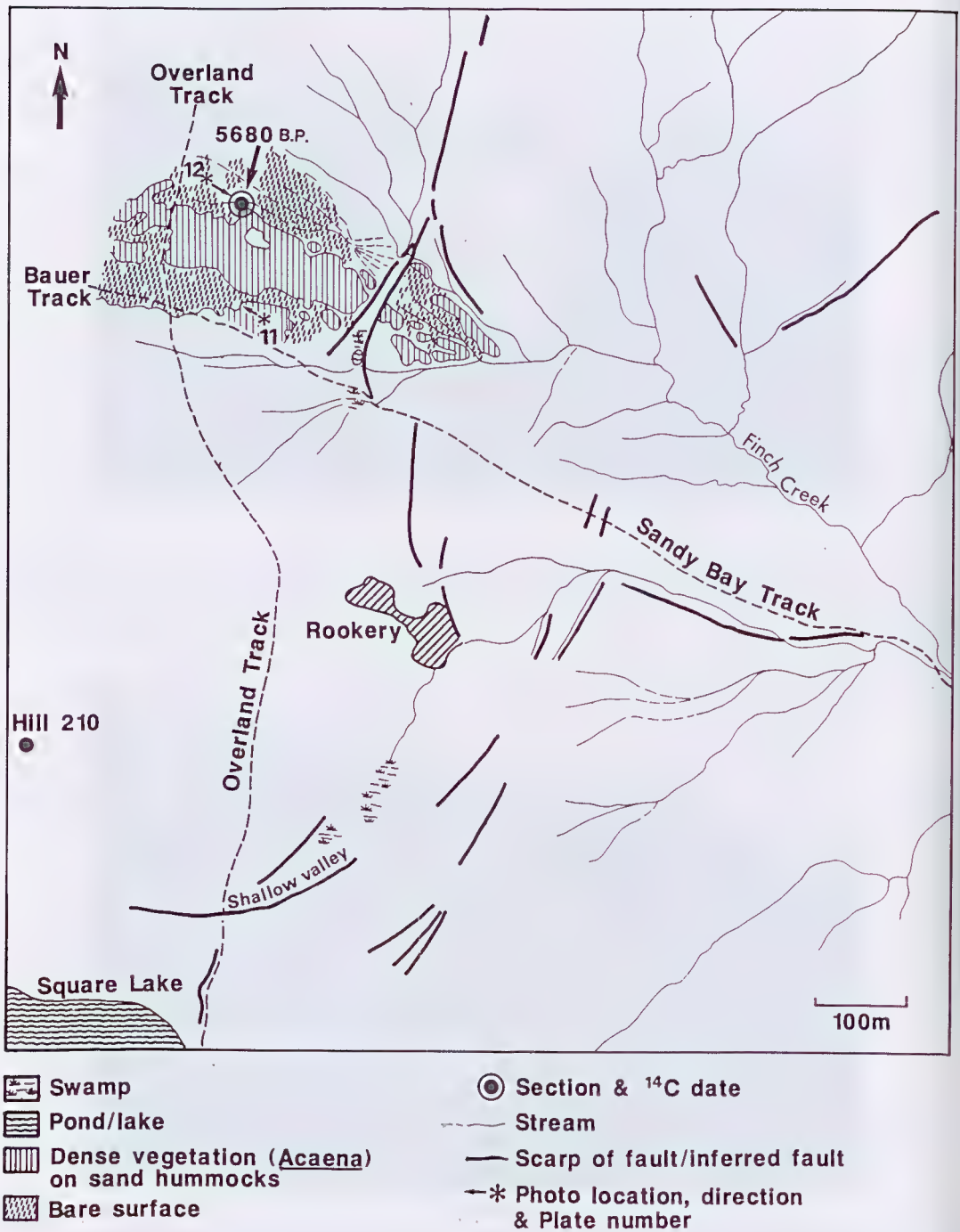
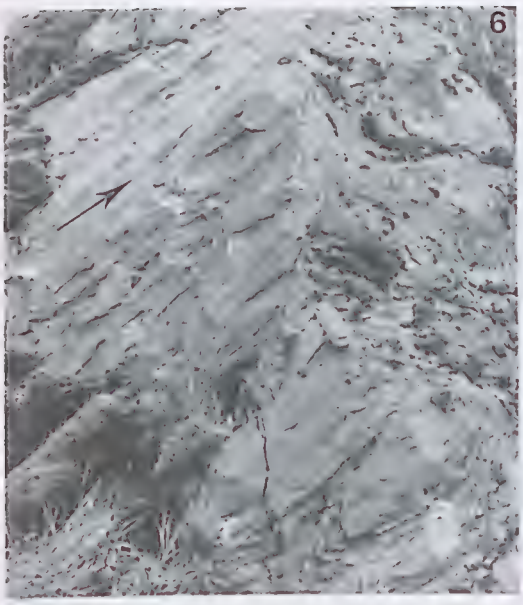
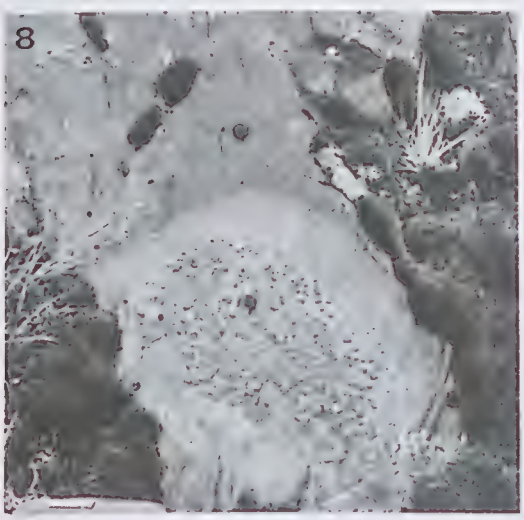


Fig. 4 — Sand and fault scarp distribution in the upper part of Finch Creek on the eastern side of the island. The dated peat (Beta 20159: 5680 ± 80 B.P.) occurred beneath 6.52 m of sand transported from upslope (west), probably mainly by wind action.





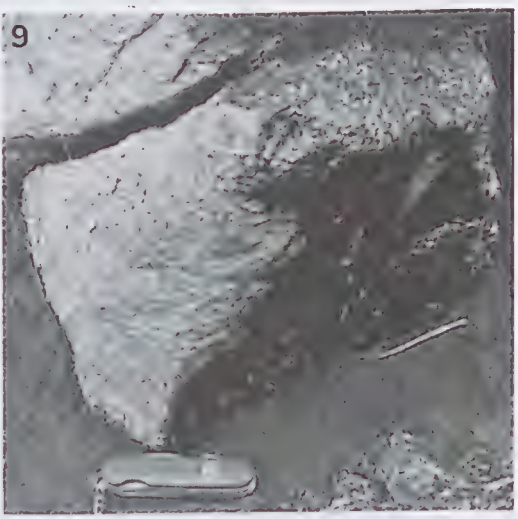


PLATE 6

Wind-polished rock surface to the left (westnorthwest) of the ridge, to the right there is no polish. The pocket knife in plates 6, 7 and 8 is 80 mm long. Arrow shows present dominant wind direction. Location of plates 6, 7 and 8 is shown in figure 2.

PLATE 7

Same site as plate 6, showing wind-eroded linear grooves and the polished rock surface. The pointed end of each groove (small arrows) is downwind. Present dominant wind direction is parallel to the long axis of the grooves.

PLATE 8

Lichen and moss growing over the wind-polished surface of the rock.

PLATE 9

Wind-polished surface on the windward (left) side of rock about 100 m from the present shore in Bauer Bay. Location shown in figure 5. Knife 80 mm long.

PLATE 10

The view westwards over Bauer Bay and the marine terrace from the sand hummock area at the edge of the plateau (fig. 2). Bauer Bay hut (arrowhead), the wind-polished rocks (small arrow), and the approximately north and south limits of figure 5 (large arrows) are indicated.

vegetated by *Poa foliosa* on the plateau (fig. 2, location of plate 10), and lies about 300 m northnortheast along the plateau edge from the ventifacted rocks. This area merits thorough investigation.

TECTONIC LANDFORMS

Faulting has affected landforms on Macquarie Island (Ledingham & Peterson 1984). The Bauer Bay–Sandy Bay region is crossed by a major, possibly faulted, geological contact between basalt and pillow lavas to the south and intrusive rocks to the north (Varne & Rubenach 1972, Christodoulou *et al.* 1984, Crohn 1986). The eastern half of the region shown in figure 1 contains numerous curving linear scarps ranging from one to many metres in height, which we interpret as fault scarps. They traverse the undulating topography, sometimes conforming to the orientation of topographic features such as streams or valleys, but also crossing hillsides, ridges and valleys to disrupt pre-existing topography. Sets of scarps often have coherent orientations over several kilometres. Some of these are undoubtedly young fault scarps with oversteepened, poorly vegetated slopes. Exposures of fault planes and breccia occasionally occur in gullies cut into these scarps.

Most scarps of faults and inferred faults shown in figures 1 and 4 are not oriented in the direction of the major lithological contact crossing the island between Bauer and Sandy Bays, suggesting that this major geological boundary has not been active in the recent past. Recent fault movement has occurred most commonly in a northnorthwest to northeast direction in this part of the island.

The curving scarp that is crossed by the Overland Track just northeast of Square Lake and southeast of Hill 210 forms the southern side of a shallow valley leading down to the uppermost royal penguin rookery and into a branch of Finch Creek. Two further traces of this lineament curve northward and cross the ridge occupied by the Sandy Bay Track. Here the lineaments are expressed as slight but distinct notches on the ridge crest. The continuity of these lineaments is clear on aerial photographs. These may be interpreted as fault scarps, and the shallow valley as fault-bounded. Colhoun & Goede (1974, plate 3) interpreted this valley as a meltwater channel cut into the rock of the southeastern spur of Hill 210 during retreat of ice from the Finch Creek valley to Square Lake. Ledingham & Peterson (1984, p.230) thought that a small corrie glacier may have existed in this area, one of the very few areas on Macquarie Island where they considered that glaciation may have occurred. The present authors prefer a tectonic explanation for this lineament, because of the apparent continuity from the wall of the shallow valley to the notches in the ridge referred to above

PLATE 11

Sand hummocks (location fig. 4) vegetated by Acaena magellanica. *The person is standing in a narrow trough between adjacent hummocks. Sand blown from the west (background) accumulates on the hummocks, or overwhelms the vegetation (right-hand foreground).*

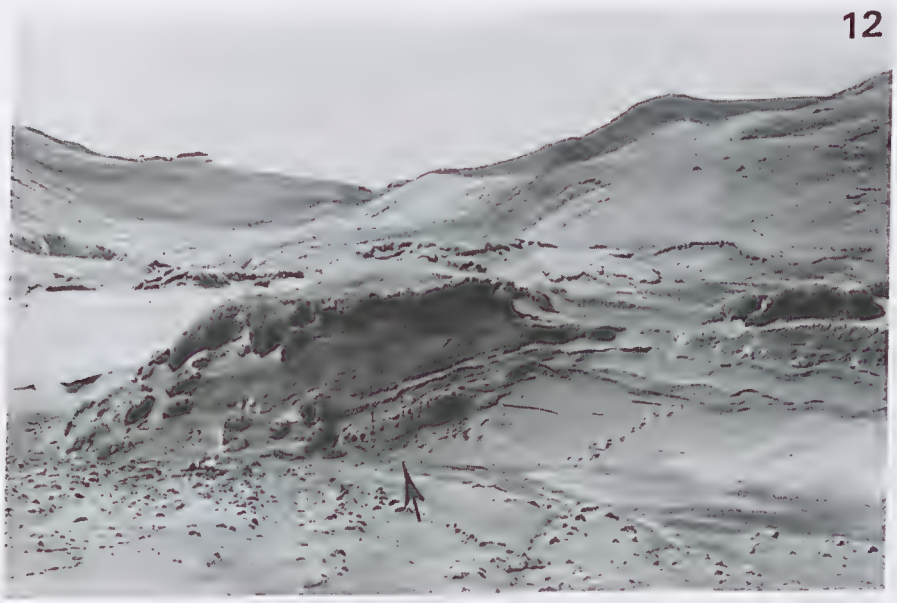


PLATE 12

An eroded sand deposit in the headwaters of Finch Creek, looking eastsoutheast into Sandy Bay. Buried sandy peat horizons with undulating surfaces are visible in the exposure. A radiocarbon date of 5680 ± 80 B. P. (Beta 20159) was obtained from near the base of the sand (arrow), 6.52 m below the present vegetation.

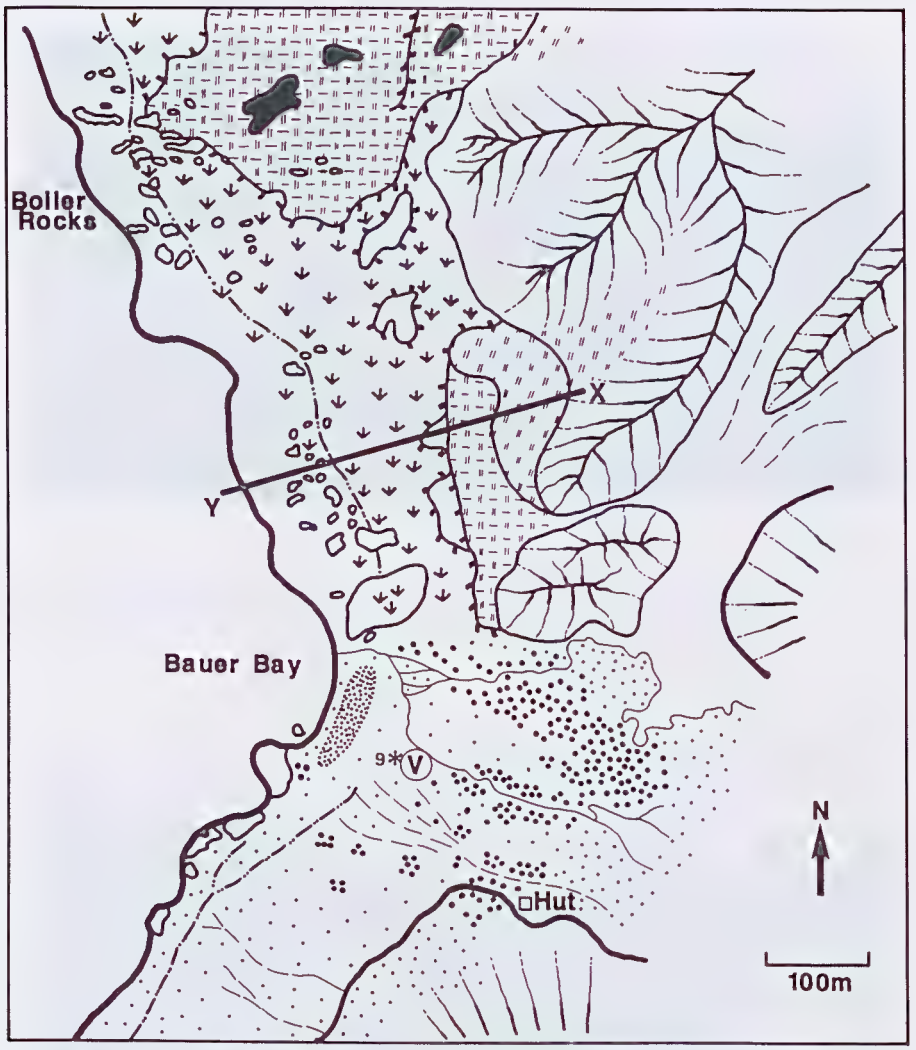


Fig. 5 — The raised marine terrace at Bauer bay, mantled by sand and mire. Section XY is figure 6.

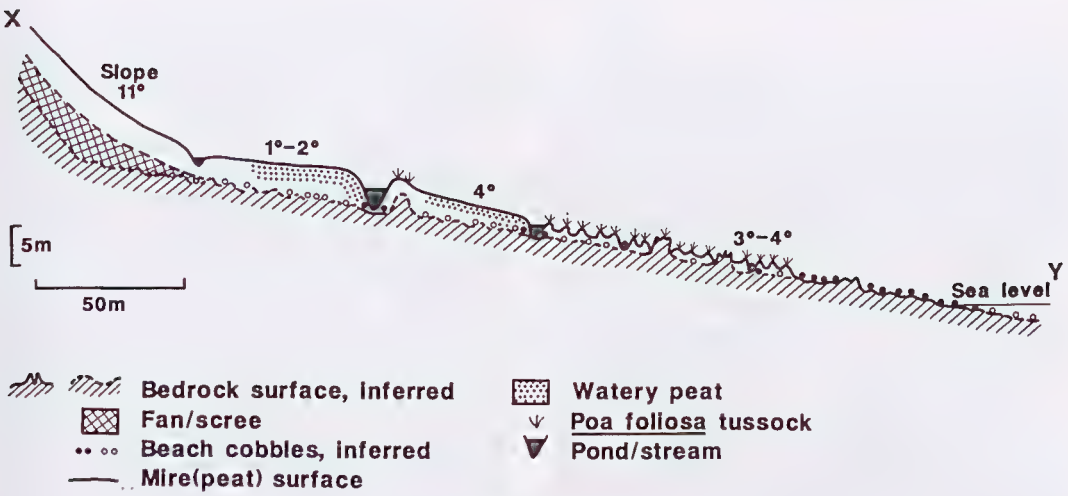


Fig. 6 — Section XY (fig. 5).

(fig. 4), and conclude that landforms in this area show evidence of tectonic activity not glaciation.

This is particularly obvious near the head of Finch Creek, where displacement along minor fault scarps disrupts drainage and sand distribution (fig. 4). There is minor ponding and swamp formation between the faults, and disruption of drainage and sand accumulation upslope and below them. Slightly offset faults continue southwards as low scarps, one forming the eastern edge of the royal penguin rookery.

MARINE LANDFORMS

On the northwest coast of the island, a terrace or platform up to 1 km wide rises gently, at slopes of 2° to 4°, from the shoreline to about 15 m a.s.l. (figs 5 and 6, plate 10). The platform is backed by steep slopes or cliffs at the plateau margin. It is mantled by rounded cobbles which can be located most easily where drainage channels and ponds prevent thick peat accumulation. The terrace is also dotted with numerous rock stacks. It is inferred that wave action in the past cut the platform, rounded the cobbles which mantle it, etched the stacks, and formed the steep slopes and cliffs by eroding their bases. The broad, gently-sloping platform and the steep slopes at its back are landforms of coastal erosion.

The steep slopes have been modified by water erosion and earthquakes to produce fan and scree deposits mantling the inner edge of the platform (fig. 6). At the head of Bauer Bay, the platform is covered by sand, now being redistributed by wind and water erosion. Here Colhoun & Goede (1973) determined the altitude of a former upper marine limit as 9 m above present sea level. The less sheltered conditions away from the head of the bay may help account for the slightly higher limit now estimated at transect XY (figs 5 and 6). Away from Bauer Bay, cover on the terrace is a complex mosaic of ponds, drainage channels and various types of mire. Vegetation on the platform includes wet tussock grassland of *Poa foliosa*, forming rough hummocky surfaces over large areas, particularly near the shore. Elsewhere the vegetation has a smoother surface covered by a wide range of plant communities, depending on hydrology, from relatively well-drained herbfield to water-saturated quaking bogs and vegetation-filled ponds (figs 5 and 6; Taylor 1955, fig. 6). Plant alliances and associations on the marine terrace have been described by Taylor (1955).

THE AGE AND ORIGIN OF LANDFORMS

Global sea-level fluctuations and uplift of the island are two independent processes which set constraints on the development and age of Macquarie Island landforms. Global sea-level fluctuations are well known in general terms (Chappell 1983). Radiocarbon dating of uplifted deposits that were once near sea level gives estimates of Holocene uplift rates for the island (Colhoun & Goede 1973, Selkirk *et al.* 1983, Bergstrom 1986).

For the main island, radiocarbon dating gives estimates ranging from 1.5 to 6 $mm a^{-1}$. The authors of this paper find the lower end of the published range of rates for uplift of the main island more plausible in the light of field observa-

tions in 1986–87. A second method of estimating uplift rate depends upon measuring the present altitude above sea level of wave-cut features that were being formed when the sea reached its present high level, about 6000 to 7000 years ago. The landward edge of the rock-cut marine terrace north of Bauer Bay is estimated to be between 10 and 20 m a.s.l. (fig. 6). Colhoun & Goede (1973) measured an upper marine limit in the sandy area at the head of Bauer Bay of 9 m. Altitudes between 10 and 20 m give uplift rates between 1.7 and 3.3 mma^{-1}. For the purposes of this discussion two values, 3 mma^{-1} and 4.5 mma^{-1} (Colhoun & Goede's (1973) maximum rate), are arbitrarily selected.

Figure 7 superimposes average uplift rates for the island, assuming no tilting, of 4.5 and 3 mma^{-1} upon the global sea-level curve for the late Quaternary (Chappell 1983). It focusses on two main locations, the landward edge of the marine-cut rock terrace at between 10 and 20 m altitude, and the sand sheet on the plateau at between 100 and 120 m altitude.

The relation between sea-level rise and island uplift could explain the genesis of the broad, gently-sloping coastal terrace. For much of the time between 15 000-16 000 and 7000-8000 years ago sea level rose faster than the land by at least 10 mma^{-1} (fig. 7). The result may have been prolonged and extremely vigorous marine erosion of the coast of the already elevated island, reflected by unusually rapid coastal cliff retreat, dispersal of the collapsed debris by wave action, and the planation of a bedrock terrace with a slope determined by the rate of gain of sea over land and the resistance of the bedrock to erosion. The measured seaward slope of the terrace ranges from about 1.5° to 4°. The width of the terrace depended on the duration (some 8000 years) of vigorous erosion by the rapidly rising sea. The base of the existing steep slopes and cliffs marks the end of terrace formation which occurred when sea level stabilised 6000 to 7000 years ago, but the land kept rising. The full width of the terrace can be estimated from the length of time when it was presumed to be forming (about 8000 years), the gain of sea over land during that time (about 10 mma^{-1}), and the terrace's slope (between 1.5° and 4°). These values predict widths between about 1000 and 3000 m. The width now exposed above sea level north of Bauer Bay ranges from about 200 to 1500 m. The model proposed, therefore, predicts that the terrace extends offshore, at the same slope as onshore, for between two and five times its onshore width. Its seaward edge probably lies between 70 and 120 m below present sea level. The few soundings northwest of the island are consistent with these predictions, but detailed soundings, which the authors hope to carry out in the future, would provide a simple test of the model.

According to this model, during the period when sea level was rising rapidly relative to the land, a strip of high plateau equal to the width of the terrace was destroyed by the sea continually eroding the base of the retreating plateau. In this way, former lakes on the plateau were destroyed, explaining the presence of fragmentary terminal Pleistocene and early Holocene lake deposits, now exposed at the top of the cliffs, and steep slopes flanking the plateau (Selkirk, Selkirk, Bergstrom & Adamson, this volume). Valleys such as that of Stony Creek were also deepened. A problem with this model is that it requires very high rates of cliff retreat of between 100 and 400 mm per annum. A combination of steady net submergence, fault-fractured and crushed rock, and the extremely high wave energy on a west-facing coast at 54°S may make this possible.

Debris from rapidly retreating cliffs would have been effectively reworked by wave action. While much would have been lost into deep water, long-shore drift and local wave action would have delivered copious sand to the Bauer Bay region where the prograding sea pushed it landwards into Bauer Bay. The sand sheet on the plateau between Bauer Bay and the head of Finch Creek and the wind-polished rocks at about 100 m altitude on the plateau edge may have originated in the early Holocene, if the volume and rate of sand arriving onshore was sufficient to overwhelm vegetation and allow sand to climb onto the plateau. The age of about 7000 years ago on peat beneath the sand sheet (Beta 20167) is consistent with this suggestion. Alternatively the high-level sand may derive from an earlier period about 40 000 years ago, or earlier, during emergence of this upper part of the island from the sea (fig. 7). Radiocarbon dates obtained from peats buried in or below these sands do not yet distinguish between these two possibilities because of possible reworking of the sand deposit, but the cobble beach below the sand (Beach 5 of Ledingham & Peterson 1984) almost certainly dates from the earlier period. Research in this interesting area may further resolve the age and origin of the sand sheet. What is plain from the dated peats included in the sands is that the sand was present and being reworked eastwards from between 6000 and 7000 years ago to the present.

The presence of the broad, partly emerged marine terrace along the northwestern coast implies relatively uniform uplift since formation of the

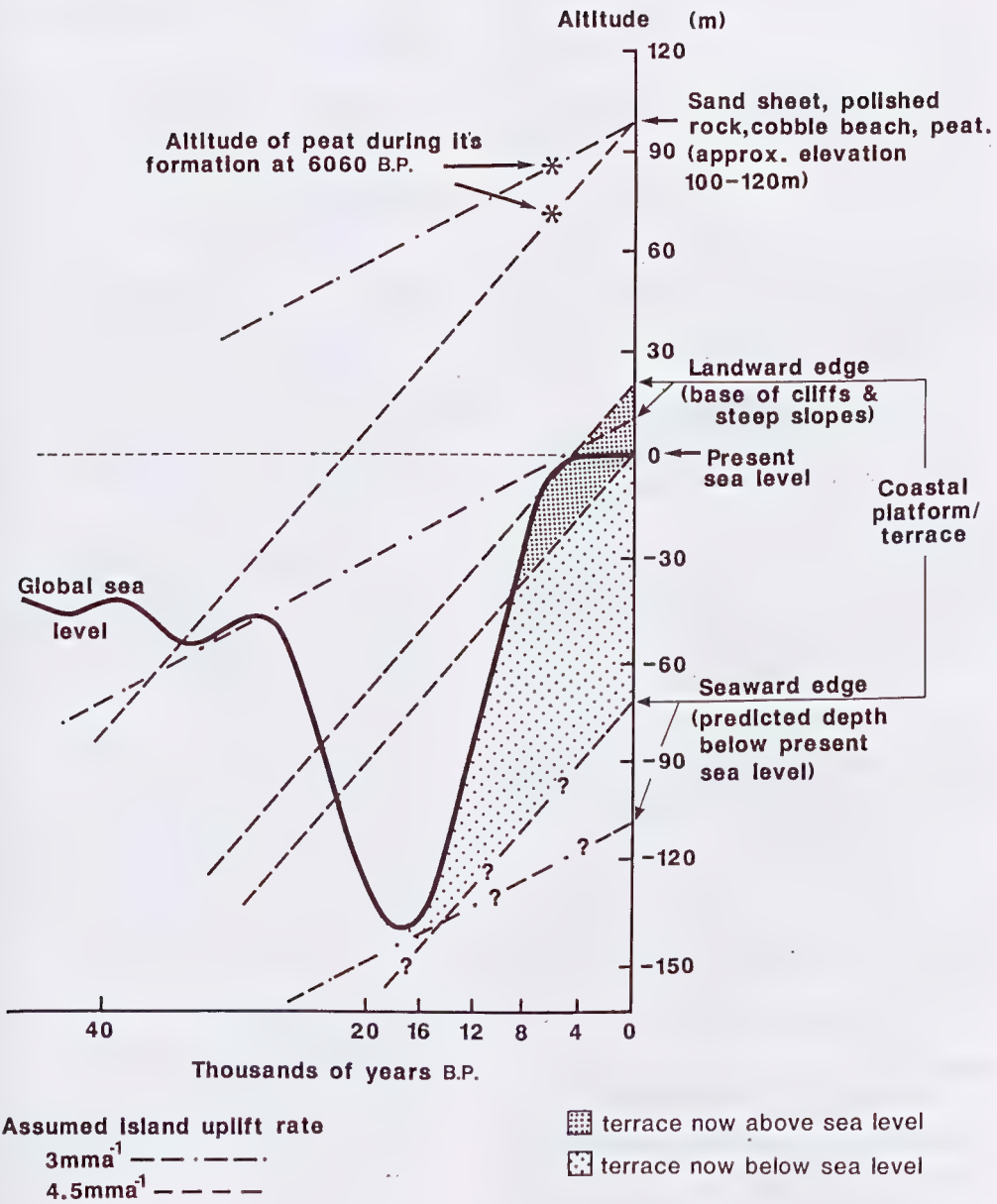


Fig. 7 — The relation between time, global sea level and the level of the land north of Bauer Bay during the terminal Pleistocene and Holocene. The sea-level curve is highly simplified. Stippling shows the terrace cut by marine erosion; an uplift rate of 4.5 mma and an upper limit of former marine erosion of 20 m above present sea level are assumed. Alternative time lines for the terrace are shown assuming values of 3 mma^{-1} and 10 m. Two estimates of the altitude of the dated peat (Beta 20167) on the plateau north of Stony Creek at the time of its formation are also shown. With the uplift rates adopted, the cobble beach would have been at sea level about 40 000 years ago or earlier.

terrace began about 16 000 years ago, according to the model we presently favour. As the exposed landward fringe of the terrace is preserved undisrupted, differential vertical movement along faults must have been minor during and since its formation. The absence of a broad raised terrace on the east coast implies more active differential vertical movement on faults, the absence of steady uplift during the period when sea level was rising rapidly, slight tilting of the island downwards to the east, or a combination of these processes. Fault movement on the island parallel and close to the east coast is active today. The major western faulted margin of the island block must lie west of the marine terrace.

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REFERENCES

ADAMSON, D.A. & PICKARD, J., 1986: Physiography and geomorphology of the Vestfold Hills. *In* Pickard, J. (Ed.): *ANTARCTIC OASIS, TERRESTRIAL ENVIRONMENTS AND HISTORY OF THE VESTFOLD HILLS.* Academic Press, Sydney: 99–136.

BERGSTROM, D.M., 1986: The Holocene vegetation history of Green Gorge, Macquarie Island. M.Sc. thesis, Macquarie University, New South Wales.

BOROWKA, R.K., 1980: Present day dune processes and dune morphology on the Leba Barrier, Polish coast of the Baltic. *Geografisker Annaler*, 62A: 75–82.

CHAPPELL, J., 1983: A revised sea-level record for the last 300,000 years from Papua New Guinea. *Search*, 14: 99–101.

CHRISTODOULOU, C., GRIFFIN, B.J. & FODEN, J., 1984: The geology of Macquarie Island. *ANARE Res. Notes*, 21. Antarctic Division, Kingston, Tasmania.

COLHOUN, E.A. & GOEDE, A., 1973: Fossil penguin bones, 14C dates and the raised marine terraces of Macquarie Island: some comments. *Search*, 4: 499–501.

COLHOUN, E.A. & GOEDE, 1974: A reconnaissance survey of the glaciation of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 108: 1–19.

CROHN, P.W., 1986: The geology and geomorphology of Macquarie Island with special emphasis on heavy metal trace element distribution. *ANARE Res. Notes*, 39. Antarctic Division, Kingston, Tasmania.

DUNCAN, R.A. & VARNE, R., 1988: The age and distribution of the igneous rocks of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 45–50.

HAMILTON, H., 1926: Ecological notes and illustrations of the flora of Macquarie Island. *AAE Sci. Rep.*, Ser. C, VII(5).

JONES, T. & McCUE, K., 1988: Seismicity and tectonics of the Macquarie Ridge. *Pap. Proc. R. Soc. Tasm.*, 122(1): 51–57.

JUNGERIUS, P.D., VERHEGGEN, A.J.T. & WIGGERS, A.J., 1981: The development of blowouts in De Blink, a coastal dune area near Noordwijkerhout, The Netherlands. *Earth Surface Processes and Landforms*, 6: 375–396.

KLEIN, J., LERMAN, J.C., DAMAN, P.G. & RALPH, E.K., 1982: Calibration of radiocarbon dates: tables based on consensus data of the workshops on calibrating the radiocarbon timescale. *Radiocarbon*, 24: 103–150.

LEDINGHAM, H. & PETERSON, J.A., 1984: Raised beach deposits and the distribution of structural lineaments on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 118: 223–235.

MAWSON, D., 1943: Macquarie Island: its topography and geology. *AAE Sci. Rep.*, Ser. A(V).

PICKARD, J., 1982: Holocene winds of the Vestfold Hills, Antarctica. *N.Z. J. Geol. Geophys.*, 25: 353–358.

SELBY, M.J., 1977: Transverse erosional marks on ventifacts from Antarctica. *N.Z. J. Geol. Geophys.*, 20: 949–969.

SELKIRK, D.R., SELKIRK, P.M., BERGSTROM D.M. & ADAMSON, D.A., 1988: Ridge top peats and palaeolake deposits on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1):

SELKIRK, D.R., SELKIRK, P.M. & GRIFFIN, K., 1983: Palynological evidence for Holocene environmental change and uplift on Wireless Hill, Macquarie Island. *Proc. Linn. Soc. N.S.W.*, 107: 1–17.

TAYLOR, B.W., 1955: The flora, vegetation and soils of Macquarie Island. *ANARE Rep.*, Ser. B(II), Botany.

VARNE, R. & RUBENACH, M.J., 1972: Geology of Macquarie Island and its relationship to oceanic crust. *In* Hayes, D.E. (Ed.): *ANTARCTIC OCEANOLOGY, II, THE AUSTRALIAN-NEW ZEALAND SECTOR.* Antarctic Research Series, American Geophysical Union, 19: 251–266.

WHITTOW, J.B., 1984: *THE PENGUIN DICTIONARY OF PHYSICAL GEOGRAPHY.* Penguin Books, Harmondsworth, England.

WILLIAMSON, P.E., 1988: Origin, structural and tectonic history of the Macquarie Island region. *Pap. Proc. R. Soc. Tasm.*, 122(1): 27–43

(accepted 16 November 1987)

RIDGE TOP PEATS AND PALAEOLAKE DEPOSITS ON MACQUARIE ISLAND

by D.R. Selkirk, P.M. Selkirk, D.M. Bergstrom and D.A. Adamson

(with one table, three text-figures and one plate)

SELKIRK, D.R., SELKIRK, P.M., BERGSTROM, D.M. & ADAMSON, D.A., 1988 (viii): Ridge top peats and palaeolake deposits on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 83–90, 1 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. School of Biological Sciences and Quaternary Research Unit, Macquarie University, New South Wales, Australia 2109.

Palynological analyses of two ridge top peat profiles on subantarctic Macquarie Island are presented and discussed. The profiles record Holocene vegetation changes in a small-scale mosaic pattern.

Older records of island vegetation should be sought in valley and lake deposits. A preliminary account is given of several freshwater palaeolake deposits dating from the terminal Pleistocene and early Holocene.

Key Words: peat deposits, palaeolake deposits, Macquarie Island, palynology.

INTRODUCTION

Contrary to earlier views (Mawson 1943, Colhoun & Goede 1974, Löffler & Sullivan 1980, Crohn 1986) that glaciation was an important factor in landscape evolution on subantarctic Macquarie Island, it is now clear that structural control by faulting and tectonic movement is probably a major force responsible for development of the present landscape (Ledingham & Peterson 1984, Christodoulou *et al.* 1984).

Information about tectonic uplift of localised sections of the island has come from several studies. Colhoun & Goede (1973), using data from McEvey & Vestjens' (1973) study of fossil penguin bones and their own studies of peat, calculated an uplift rate of 1.5–4.5 mm/yr for coastal beach terraces at Bauer Bay and Green Gorge. Bergstrom (1985), using evidence from plant microfossils and seal hairs in peat, calculated an uplift rate of 3–6 mm/yr for sites at Green Gorge. Selkirk *et al.* (1983), on the basis of evidence from plant microfossils in peat overlying a raised beach, calculated an uplift rate of 14.5 mm/yr for Wireless Hill, an isolated fault block at the northern end of the island.

The tectonically active nature of the island has implications for any further geomorphological and palaeontological studies. An extensive landslip occurred near the sampled profile at Green Gorge in early 1986 (plate 1). We suggest that peats on ridge tops on Macquarie Island are unlikely to preserve long vegetation records (table 1, p. 89), since they occur in sites very susceptible to landslip during earthquakes and/or periods of heavy rain. Ridge top accumulation sites in active tectonic environments are inherently unstable. Both ridge top sites described in this paper are adjacent to active fault zones (see Finch Creek site in fig. 4, Adamson *et al.*, this volume).

Longer sedimentary and fossil records (table 1) are more likely to be found in lakes and on valley floors than elsewhere on the island, but here too, because of tectonic activity, the records may not be as old as expected. There is also the complication that, in valley sites, landslips may superimpose older peat from ridges on younger valley peats.

Reports on material from two ridge top peat sites and four fossil lake deposits are presented below.

RIDGE TOP PEATS

Numerous peat exposures occur on ridge tops on Macquarie Island. They often form almost vertical faces, exposed by wind erosion, with weathered bedrock at the base and modern vegetation on top. Such exposures allow sampling from freshly cut, vertical faces. Two deposits have been analysed: one from a ridge at about 100 m a.s.l. on the southern rim of the Green Gorge basin (54°38′S, 158°54′E), between the Overland walking track and Sawyer Creek; the other from a ridge on the southern side of Finch Creek valley (54°34′S, 158°55′E) (fig. 1). Results of the analyses are given in figures 2 and 3. Standard palynological techniques (Brown 1960) were used to extract pollen for study.

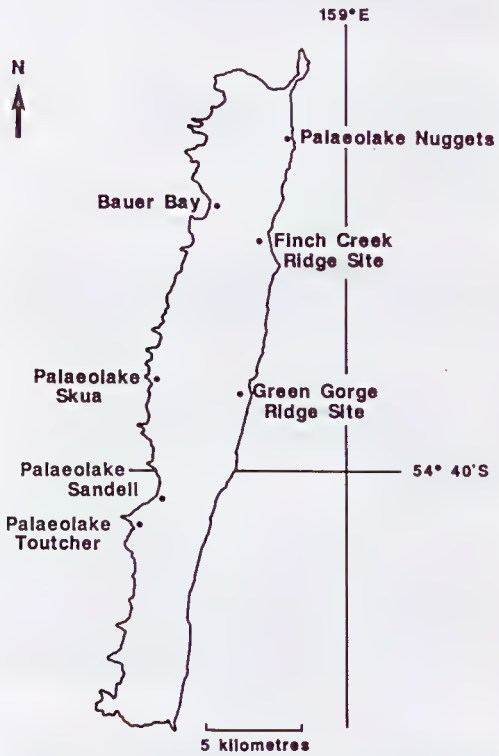


FIG. 1 — Macquarie Island showing study sites.

Modern vegetation topping the peat on the Green Gorge ridge site is short grassland, with *Luzula crinita*, *Festuca contracta*, *Acaena magellanica* and *A. minor*, *Poa foliosa*, *Cerastium fontanum*, *Uncinia sp.*, and the mosses *Campylopus introflexus*, *Orthodontium lineare* and *Thuidium furfurosum*. *Stilbocarpa polaris* and *Pleurophyllum hookeri* occur close by. The Finch Creek exposure is similarly topped by short grassland vegetation.

Vegetational changes recorded in both profiles are interpreted as representing small-scale community dynamics in herbfield or grassland. Both profiles show fluctuations between vegetation dominated by *Stilbocarpa* and/or *Acaena* (Green Gorge exposure) or *Stilbocarpa* alone (Finch Creek) and grassland. The grassland represented in the Green Gorge profile is probably short grassland: seeds of *Luzula* occur in the peat and *Luzula crinita* is at present a dominant in the short grassland. *Stilbocarpa* and/or *Acaena* often dominate herbfields. Short grassland and herbfield often occur in local mosaics.

Several authors have interpreted vegetation changes on Kerguelen in terms of climatic change, often over very short time spans (Bellair & Delibrias 1967, Roche-Bellair 1973, 1976a, b, Young & Schofield 1973). High percentages of *Azorella* pollen coupled with low percentages of *Acaena* have been interpreted as indicating cooler periods on Kerguelen (Roche-Bellair 1976a, b, Young & Schofield 1973) and in the Crozet Archipelago (Roche-Bellair 1973).

There is no need to invoke climatic change to explain the vegetational changes shown in the Green Gorge and Finch Creek profiles. They are best interpreted as representing successional or local changes within communities. Many subantarctic plant species which produce morphologically distinct pollen, easily recognisable in the pollen record (e.g. *Azorella*), have wide ecological tolerances (Barrow & Smith 1983, Pickard *et al.* 1984). Aubert de la Rue (1964) described *Azorella* in Kerguelen as growing at all altitudes from sea level to 840 m. *Azorella selago* is a coloniser of bared surfaces in Kerguelen (Roche-Bellair 1976a, Aubert de la Rue 1964). Huntley (1972) recorded *Azorella* in all communities on Marion Island and regarded it as a pioneer species, providing a substrate for less hardy species. Copson (1984) found *Azorella selago* to be very widespread on Macquarie Island. It occurs on large rocks at low altitudes, where interspecific competition is low, through to high altitudes, where the species is widespread in the feldmark. We believe the basal peak in *Azorella* pollen in each of the profiles studied represents vegetation establishment on bared surfaces.

Dating of Deposits

The Finch Creek ridge site was sampled on three occasions from three trenches (*a*, *b*, *c*), each trench more than 1 m from its neighbour (table 1). Good agreement was obtained in dating corresponding layers from successive samplings, except for the basal date in sampling *a*.

Selkirk & Selkirk (1983) reported the basal date of the Finch Creek ridge deposit described here as 10 275 ± 230 years B.P. (Beta-1386). The site was resampled on two occasions to test the validity of this date, as there seemed to be the possibility of a hiatus in accumulation between the basal layer and the 127 cm level. Basal peats collected on later occasions yielded dates far younger than 10 000 years B.P. Beta-1386 was obtained on a sample of only 0.4 g of carbon. The discrepancy between Beta-1386 and other dates

PLATE 1

In early 1986 a landslip removed an extensive area of peat from the eastern side of the ridge the top of which had been earlier sampled as the Green Gorge ridge site. The surface was bared back to bedrock over much of its area.

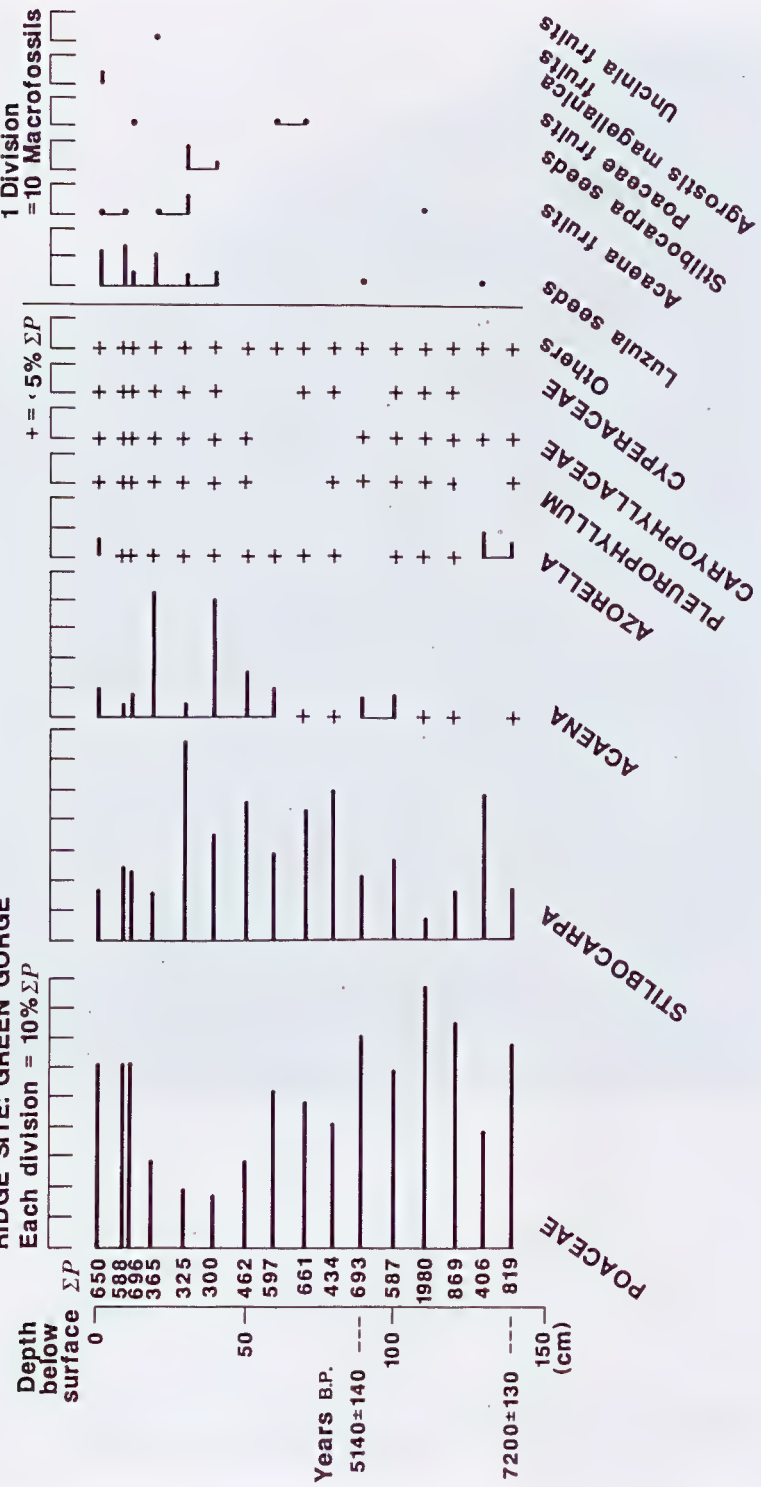


FIG. 2 — Pollen diagram for Finch Creek Ridge site. Ages in radiocarbon years B.P. Calibrated ages and laboratory numbers in table 1.

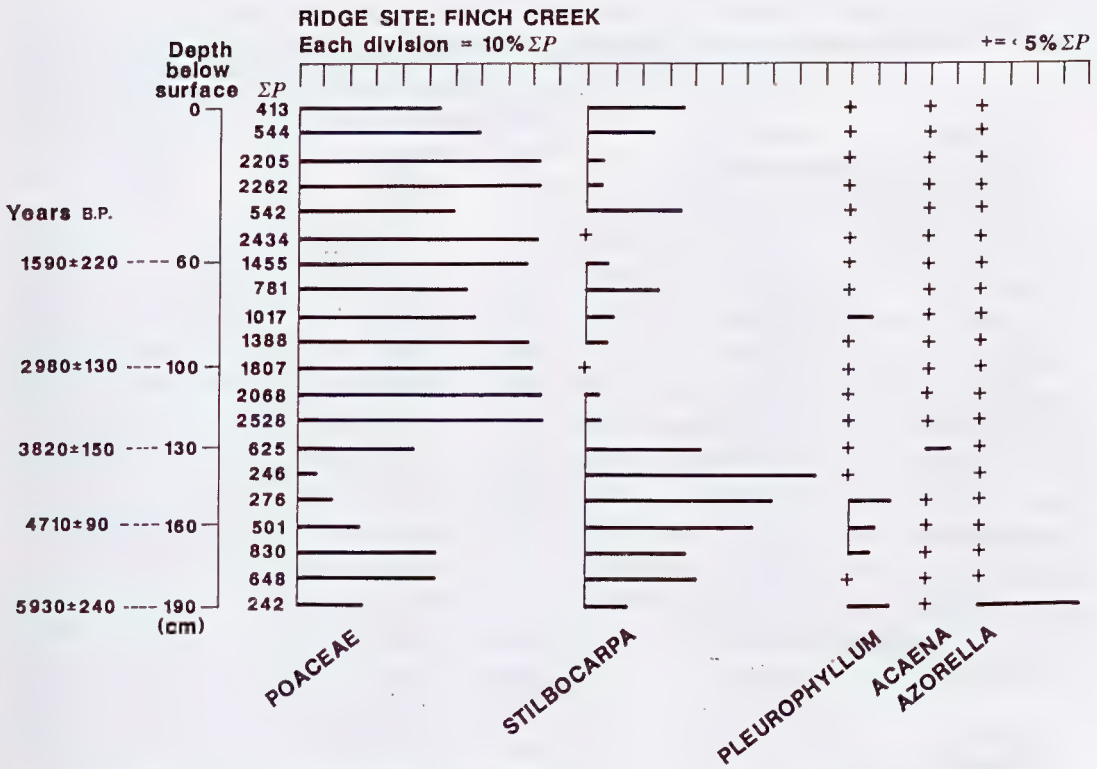


FIG. 3 — Pollen diagram for Green Gorge Ridge site. Ages in radiocarbon years B.P. Calibrated ages and laboratory numbers in table 1.

shown in table 1 probably results from a laboratory error, but could represent fortuitous inclusion of older peat in the original sample.

The Green Gorge ridge site was sampled on two occasions from two trenches 1 m apart (*a*, *b*). Sampling *b* provided a larger sample to refine the error on sampling *a* (table 1).

FOSSIL LAKE DEPOSITS

Palaeolake Skua (fig. 1)

Skua Lake and several other small lakes and ponds lie in a broad shallow basin about 180 m a.s.l. on the western edge of the plateau, west of Mt Ifould and north of Mt Waite. Skua Lake drains via a creek over the cliff into Sellick Bay. Northwest and west of the outlet creek, in the cliff on the northern side of Sellick Bay, exposed lacustrine deposits extend about 9 m above and about 5 m below the present level of Skua Lake. The lake deposits can be followed eastwards in ridges at the southwestern end of Skua Lake.

The 13.6 m of sediments are bedded, the beds dipping northeast at an angle of about 8°. We interpret the sediments as lacustrine, possibly tilted by faulting, indicating the presence of a former, larger Palaeolake Skua, which extended westwards beyond the present cliff. Preliminary examination of the bedded sediments indicates excellent preservation of microfossils (pollen, diatoms) and macrofossils (leaves of *Myriophyllum*, leaves and stems of mosses, and seeds). The fossils present indicate that the entire sequence was laid down in freshwater conditions. We suggest that Palaeolake Skua was partially drained as the western cliffline retreated eastwards, due to marine erosion, to its present position. The present Skua Lake and other small lakes and ponds in its vicinity are remnants of the more extensive Palaeolake Skua whose shoreline was at least 9 m above the present level of Skua Lake.

The lowest bed dated from the sediments of Palaeolake Skua (4.6 m above the base of the bedded deposit) gives an age of 12 470 ± 140 years

B.P. (Beta-20165) (table 1), making it the oldest material dated from Macquarie Island (cf. Colhoun 1985).

Palaeolake Sandell (fig. 1)

Palaeolake Sandell occupies a small shallow valley, about 210 m a.s.l. to the north of Major Lake. A deeply incised creek drains the present mire over the cliff into Sandell Bay. Bedded sediments are exposed in the creek bank to 3.8 m above water level in the creek on the day of sampling. A sample collected by auger from 0.4 m below the creek water level, dated at 7960 ± 110 years B.P. (Beta-20163) (table 1), contains well-preserved microfossils (phytoliths, diatoms, pollen) and macrofossils (leaves of *Myriophyllum*, *Azorella*, leaves and stems of mosses and seeds). Samples from higher levels in the deposit contain well-preserved macrofossils including small woody stems, alternately layered with sandy gravel horizons. Preliminary examination suggests that the deposit represents a mire developed above a former lake.

Palaeolake Nuggets (fig. 1)

A lacustrine deposit topped by Holocene peat forms a 4.5 m exposure in the coastal cliff 30 m a.s.l. at the head of a small gully just north of The Nuggets (Mawson 1943, Selkirk & Selkirk 1983). The sediments contain well-preserved microfossils (diatoms, pollen) and macrofossils (leaves of *Myriophyllum*, leaves and stems of mosses) and have been dated at 9400 ± 220 years B.P. (SUA-1894) (table 1) 4.4 m below the surface (Selkirk & Selkirk 1982, Pickard *et al.* 1984). Palaeolake Nuggets was sampled on two occasions (*a*, *b*). There is good agreement between dates obtained except for the 40 cm and 50 cm levels.

We interpret the deposit as a remnant of a lake which formerly extended eastwards beyond the present cliffline; a lake drained by retreat of the cliffline due to marine erosion.

Palaeolake Toutcher (fig. 1)

Just south of Cape Toutcher, a creek drains Major Lake and a series of smaller lakes and ponds south of and connected to it, then flows over the coastal cliff at about 200 m a.s.l. Diatomites and contained macrofossils exposed in the creek bed near the edge of the plateau date at 11 010 ± 200 years B.P. The bedded sediments contain well-preserved microfossils and macrofossils (leaves of Myriophyllum, stems and leaves of mosses, diatoms and pollen).

DISCUSSION

If the estimated rates of uplift for Bauer Bay and Green Gorge are considered in conjunction with the Quaternary sea-level curve (Chappell 1983) it is apparent that between about 16 000 and 6000 years B.P., sea level was rising more rapidly than the island. If the land was rising at between 1.5 and 6 mm/yr while sea level was rising at about 15 mm/yr (i.e. 150 m/10 000 yrs), erosion of sea cliffs would have been very active. We conclude that it was during this period of post-glacial sea-level rise that cliff retreat drained the palaeolakes described above.

Detailed examination of material preserved in these deposits, dating of additional layers, and sampling of lower layers, as at Palaeolake Toutcher, will allow reconstruction of environmental conditions at each site in the early Holocene and terminal Pleistocene. Preliminary conclusions are that no palaeolake site described above has been subject to marine influence and that the vegetation represented in the deposits was composed of species currently growing on the island.

ACKNOWLEDGEMENTS

Permission from the Macquarie Island Advisory Committee to conduct fieldwork on the island and logistic support from the Australian Antarctic Division are gratefully acknowledged. Financial assistance for the study was provided by the Australian Research Grants Scheme, the Antarctic Science Advisory Committee Grants Scheme, and research grants from both Macquarie and Sydney Universities. We thank G. Rankin for drafting the diagrams.

TABLE 1

Ages in Radiocarbon Years and Calibrated Ages for Organic Material* Sampled from Six Sites

Site, sampling occasion**		Depth below surface (cm)	Laboratory number	Age in radiocarbon years (B.P. ± s.d.)	Calibrated age (B.P. ± 95% confidence level)***
1. Finch Creek Ridge	b	40	SUA-1850	modern	–
	c	50	SUA-2129	280± 50	380± 95
	b	60	SUA-1849	1590±220	1545P365
	b	100	SUA-1848	2980±130	3150±365
	c	100	SUA-2128	2990± 50	3115±240
	a	127	SUA-1460	3860±140	4320±410
	b	130	SUA-1847	3820±150	4280±430
	c	150	SUA-2127	3880± 90	4340±260
	b	160	SUA-1846	4710± 90	5425±300
	a	182	Beta-1386	10275±230	–
	b	190	SUA-1845X	5930±240	6790±410
	c	190–200	SUA-2126	5630± 80	6380±280
2. Green Gorge Ridge	a	88	SUA-1462	5140±140	5805±495
	b	130	SUA-2164	7200±130	8000±525
	a	138	SUA-1461	6900±900	–
3. Palaeolake Skua		220	Beta-20166	8620±170	9420±340
		900	Beta-20165	12470±140	–
4. Palaeolake Sandell		160	Beta-20164	5220± 80	6025±290
		420	Beta-20163	7960±110	8760±220
5. Palaeolake Nuggets	b	40	SUA-2157	3920±110	4420±300
	a	50	SUA-1468	1700±110	1640±260
	b	55	SUA-2158	6850±100	7685±360
	b	70	SUA-2159	8540±130	9340±260
	b	90	SUA-1893	8300±230	9100±460
	a	150	SUA-1467	8560±200	9360±400
	b	240	SUA-1892	9000±250	9800±500
	a	340	SUA-1466	8230±240	9030±480
	b	440	SUA-1894	9400±220	10200±440
6. Palaeolake Toutcher			Beta-20162	11010±200	–

* Peat from sites 1, 2; lacustrine sediments from sites 3-6.

** a, b or c indicate trenches dug on three separate occasions, each more than 1 m from its neighbour.

*** Ages less than 8000 radiocarbon years have been calibrated following Klein *et al.* (1982); ages between 8000 and 10 000 radiocarbon years have been calibrated by adding 800 years to conventional date and doubling the standard deviation to give 95% confidence interval; ages greater than 10 000 radiocarbon years have not been calibrated.

REFERENCES

ADAMSON, D.A., SELKIRK, P.M. & COLHOUN, E.A., 1988: Landforms of aeolian, tectonic and marine origin in the Bauer Bay–Sandy Bay region of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1):65–82.

AUBERT DE LA RUE, E., 1964: Observations sur les caractères et la répartition de la végétation des îles Kerguelen. *Comité National Français des Recherches Antarctiques — Biologie*, 1 (1).

BARROW, C.J. & SMITH, R.I.L., 1983: Palynological studies in South Georgia: II. Two profiles in Sphagnum Valley, Cumberland West Bay. *Br. Antarct. Surv. Bull.*, 58: 15–42.

BELLAIR, N. & DELIBRIAS, G., 1967: Variations climatiques durant le dernier millenaire aux îles Kerguelen. *Comptes Rendus de l'Acad. Sci., Paris*, 264D: 2085–2088.

BERGSTROM, D.M., 1985: The Holocene Vegetation History of Green Gorge, Macquarie Island. Unpublished M.Sc. thesis, Macquarie University, Sydney.

BROWN, C.A., 1960: *PALYNOLOGICAL TECHNIQUES*. Privately published, Baton Rouge, Louisiana.

CHAPPELL, J., 1983: A revised sea-level record for the last 300,000 years from Papua New Guinea. *Search*, 14(3–4): 99–101.

CHRISTODOULOU, C., GRIFFIN, B.J. & FODEN, J., 1984: The geology of Macquarie Island. *ANARE Res. Notes*, 21: 1–25.

COLHOUN, E.A., 1985: Radiocarbon dates for Tasmania, 1956–1984. *Pap. Proc. R. Soc. Tasm.*, 119: 39–54.

COLHOUN, E.A. & GOEDE, A., 1973: Fossil penguin bones, 14C dates and the raised marine terrace of Macquarie Island: some comments. *Search*, 4(11–12): 499–501.

COLHOUN, E.A. & GOEDE, A., 1974: A reconnaissance survey of the glaciation of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 108: 1–19.

COPSON, G.R., 1984: An annotated atlas of the vascular flora of Macquarie Island. *ANARE Res. Notes*, 18: 1–70.

CROHN, P.W., 1986: The geology and geomorphology of Macquarie Island with special emphasis on heavy metal trace element distribution. *ANARE Res. Notes*, 39: 1–28.

HUNTLEY, B.J., 1972: Notes on the ecology of *Azorella selago* Hook. f. *J. S. Afr. Bot.*, 38: 103–113.

KLEIN, J., LERMAN, J.C., DAMAN, P.G. & RALPH, E.K., 1982: Calibration of radiocarbon dates: tables based on consensus data of the workshops on calibrating the radiocarbon timescale. *Radiocarbon*, 24: 103–150.

LEDINGHAM, R. & PETERSON, J.A., 1984: Raised beach deposits and the distribution of structural lineaments on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 118: 223–235 plus maps.

LÖFFLER, E. & SULLIVAN, M.E., 1980: The extent of former glaciation on Macquarie Island. *Search*, 11(7–8): 246–247.

MAWSON, D., 1943: Macquarie Island: its geography and geology. *AAE Res. Rep.*, Ser. A (V): 1–193.

McEVEY, A.R. & VESTJENS, W.J.M., 1973: Fossil penguin bones from Macquarie Island, southern ocean. *Proc. Roy. Soc. Vict.*, 86(2): 151–174.

PICKARD, J., SELKIRK, P.M. & SELKIRK, D.R., 1984: Holocene climates of the Vestfold Hills, Antarctica and Macquarie Island. *In* Vogel, J.C. (Ed.): *LATE CAINOZOIC PALAEOCLIMATES OF THE SOUTHERN HEMISPHERE. PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM HELD BY THE SOUTH AFRICAN SOCIETY FOR QUATERNARY RESEARCH, SWAZILAND, 29 AUGUST–2 SEPTEMBER 1983.* Balkema, Rotterdam: 173–182.

ROCHE-BELLAIR, N., 1973: Palynologie et datation d'une coupe de l'île de la Possession (Archipel des Crozet). *Comptes Rendus de l'Acad. Sci., Paris*, 276D: 713–716.

ROCHE-BELLAIR, N., 1976a: Les variations climatiques de l'holocène superieur de îles Kerguelen: d'après la coupe d'une tourbière de la Plaine de Dante (côte méridionale). *Comptes Rendus de l'Acad. Sci., Paris*, 282D: 1257–1260.

ROCHE-BELLAIR, N., 1976b: L'holocène de l'anse Betsy (îles Kerguelen). *Comptes Rendus de l'Acad. Sci., Paris*, 282D: 1347–1349.

SELKIRK, D.R. & SELKIRK, P.M., 1983: Preliminary report on some peats from Macquarie Island. *In PROCEEDINGS OF FIRST CLIMANZ CONFERENCE, FEBRUARY 1981.* Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, Canberra: 115–117.

SELKIRK, D.R., SELKIRK, P.M. & GRIFFIN, K., 1983: Palynological evidence for Holocene environmental change and uplift on Wireless Hill, Macquarie Island. *Proc. Linn. Soc. NSW*, 107: 1–17.

SELKIRK, P.M. & SELKIRK, D.R., 1982: Late Quaternary mosses from Macquarie Island. *J. Hattori Bot. Lab.*, 52: 167–169.

YOUNG, S.B. & SCHOFIELD, E.K., 1973: Pollen evidence for Late Quaternary climatic change on Kerguelen Islands. *Nature*, 245(5424): 311–312.

(accepted 2 October 1987)

THE CLIMATE OF MACQUARIE ISLAND AND ITS ROLE IN ATMOSPHERIC MONITORING

by N.A. Streten

(with four tables, fourteen text-figures and one plate)

STRETEN, N.A., 1988 (viii): The climate of Macquarie Island and its role in atmospheric monitoring. *Pap. Proc. R. Soc. Tasm.*, 122(1): 91–106, 1 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Bureau of Meteorology, G.P.O. Box 1289K, Melbourne, Australia 3001.

An analysis is made of the principal climatic elements at Macquarie Island in relation to the general circulation of the high latitudes of the southern hemisphere. The climate is characterised by a high frequency of strong west to northwesterly winds and frequent gales, low variability of temperature, a high frequency of low cloud and fog, and a high number of days with precipitation throughout the year. In general, the climate is typical of a higher mid-latitude oceanic island, and its features are compared with others in the circumpolar Southern Ocean.

From a different perspective the island occupies a unique geographic site. This makes it extremely valuable as a meteorological observatory, enabling regular surface and upper air observations for day-to-day global analysis and forecasting, and providing climatic data representative of the higher southern mid-latitudes. Despite the advent of new observational techniques (such as satellite-reporting drifting ocean buoys, satellite cloud imagery and satellite-derived atmospheric temperature profiles), the observations from Macquarie Island continue to constitute essential calibration data for space-derived measurements and provide the long-term continuity only possible at a fixed baseline station. The importance of these data is stressed, not only with respect to the standard meteorological observations but also to the measurement of ozone, carbon dioxide and other atmospheric trace constituents which are becoming increasingly recognised as significant in studies of long-term climatic change.

Key Words: Macquarie Island, climatic change, meteorological observations, Southern Ocean, O_3 "hole", CO_2 increase.

> "For days on end the upper plateau would be shrouded in mist and a great wall of fog would block out the sea on all sides. A fine misty rain would be falling continually and the inevitable wind sweeping in past the apparently inpenetrable fog barrier." (K.C. Hines, unpublished account of the first ANARE expedition of 1948)

INTRODUCTION

The weather and climate of Macquarie Island are best analysed by consideration of its geographical position relative to the broadscale atmospheric and oceanic circulation features of the Southern Hemisphere (fig. 1). Thus, its latitude (54°30'S), just north of the Antarctic Convergence, its ocean location, far removed from the major land masses of Australia and Antarctica, and also, to a lesser but still significant extent, its longitude (158°57'E) are critical in understanding the observed conditions. The present discussion will generally follow the approach of considering climatic data from the island within the framework of the broadscale general circulation of the hemisphere and also comparing it with observations at other Southern Ocean islands. Previous studies of the island's climate have been made by Newman (1929) and Kidson (1946), using data from the Mawson period (1911–14), and by Gibbs *et al.* (1952) analysing in some detail the observations of the first year of the Australian National Antarctic Research Expeditions (ANARE) in 1948. Complete observational data have been published by ANARE from 1948 to 1968, and the entire records to date are held in readily accessible form in the Bureau of Meteorology's data bank in Melbourne.

PRESSURE, WIND AND WEATHER SYSTEMS

Figure 2, based on the data of Taljaard *et al.* (1969) and Jenne *et al.* (1971), shows the mean sea-level pressure and windspeed fields over the surrounding region in January and July, and indicates that the island lies throughout the year in the regime of the mid-latitude westerlies, between the subtropical anticyclones and the subpolar belt of low pressure surrounding Antarctica. The maps also show that the longitude of Macquarie Island is upstream of the mean pressure ridge extending south of the eastern Tasman Sea and New Zealand and downstream of the trough centred south of

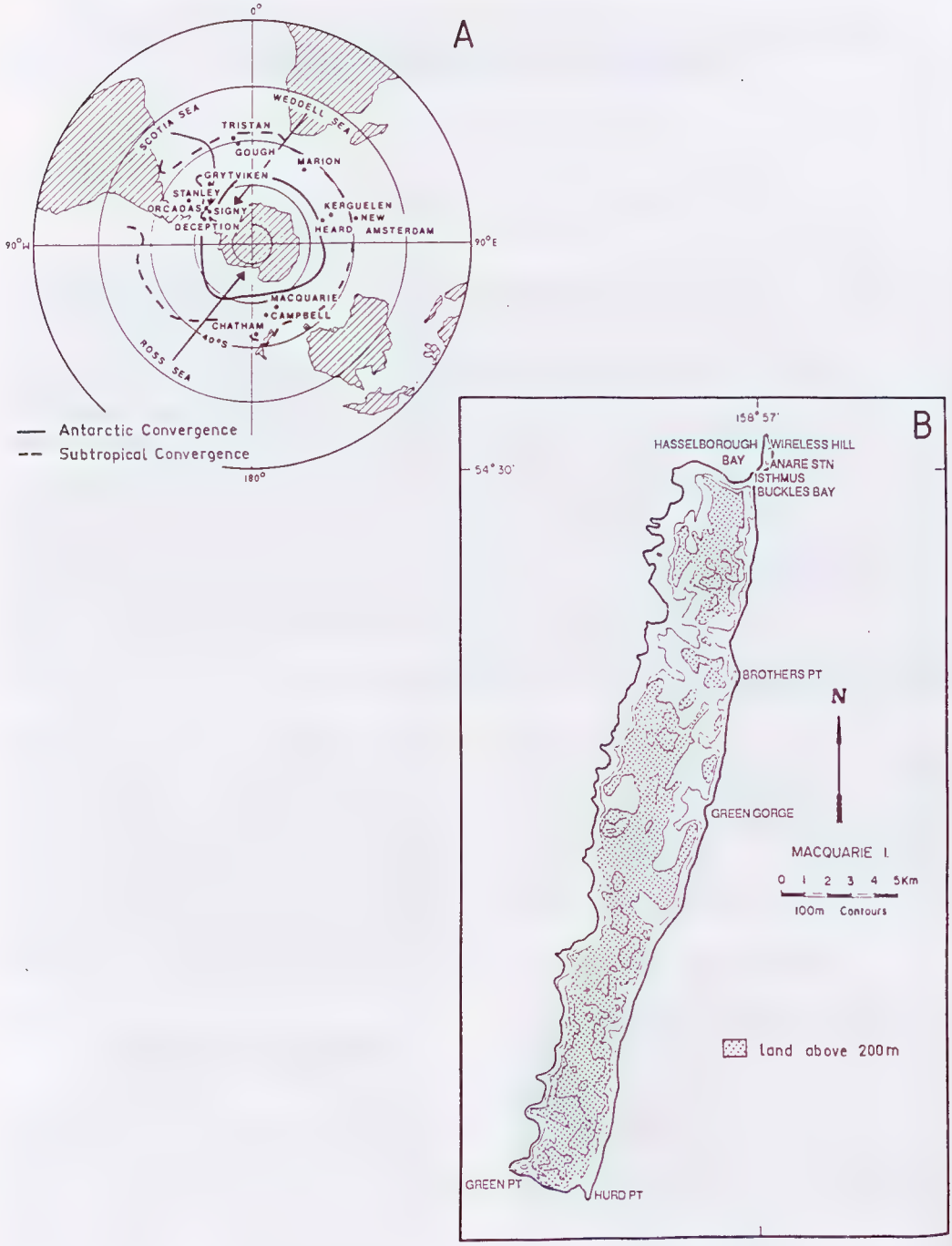


FIG. 1 — (A) The Southern Hemisphere (polar stereographic projection) showing relation of Macquarie Island to other places mentioned in the text.
(B) Macquarie Island.

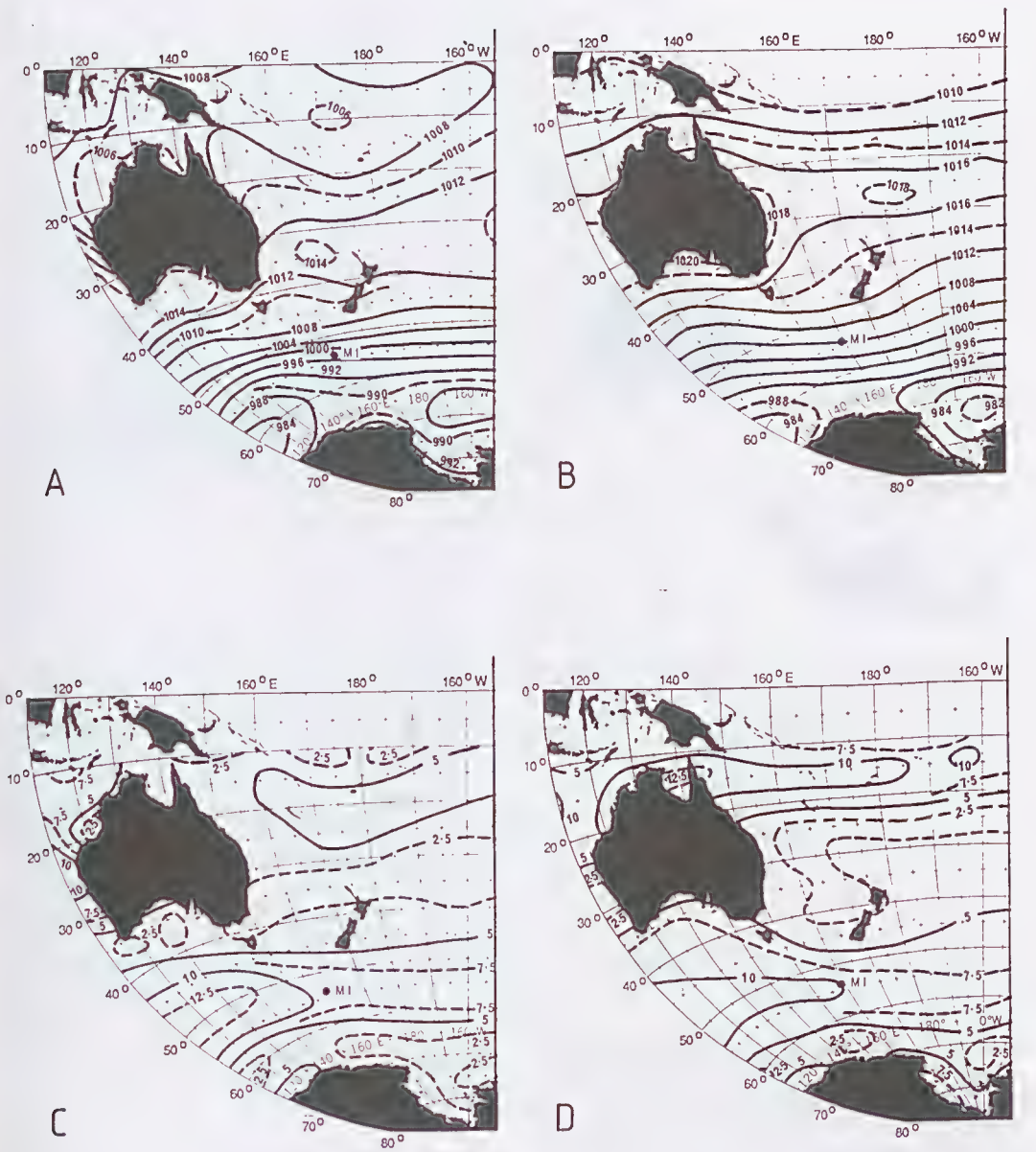


FIG. 2 — Mean sea-level pressure (hPa) in (A) January and (B) July based on data from Taljaard et al. *(1969). Mean surface geostrophic windspeed (ms^{-1}) in (C) January and (D) July based on data from Jenne* et al. *(1971). MI indicates location of Macquarie Island.*

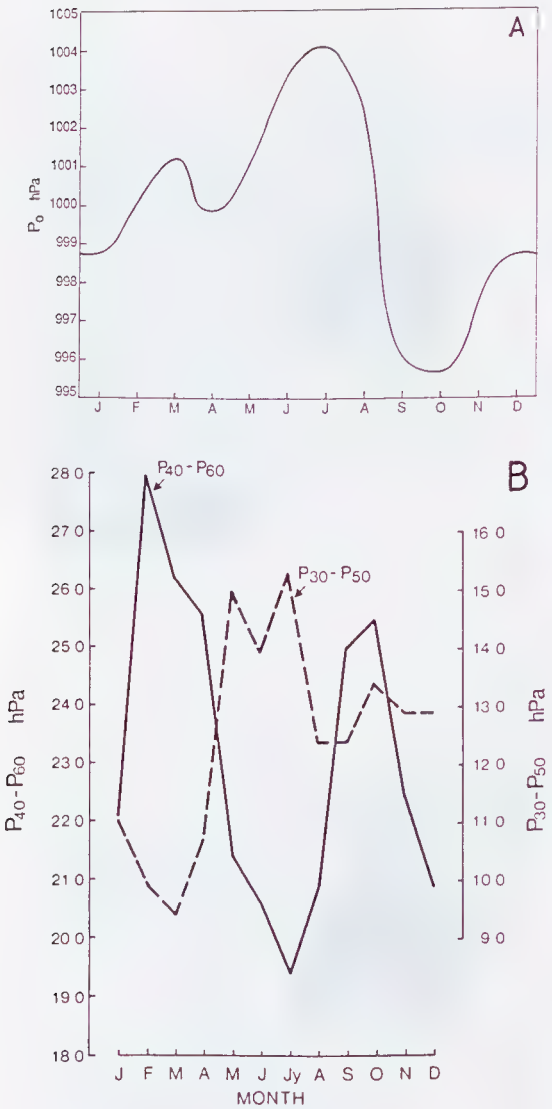


FIG. 3 — (A) Annual cycle of mean sea-level pressure (P_o) at Macquarie Island (hPa) = ½ (0900 h + 1500 h); available data 1948–83. (B) Annual cycle of pressure gradients between 40° S and 60° S and between 30° S and 50° S; (1972–77) averaged over Pacific longitudes; after Streten & Zillman (1984).

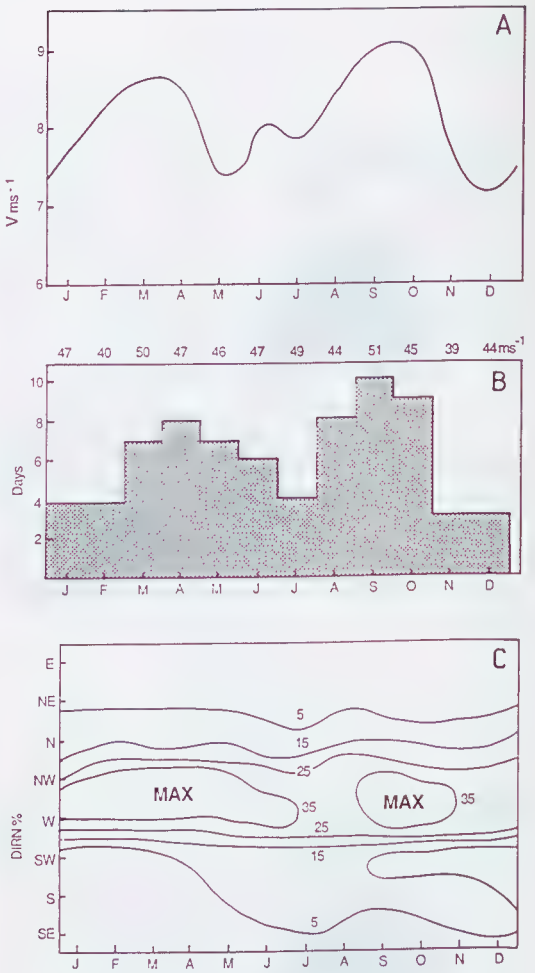


FIG. 4 — Wind data for Macquarie Island. (A) Mean windspeed V; all years 1948–83. (B) Mean number of days of gale (i.e. days with winds >17.5 ms^{-1}) for the period 1967–83; figures above the histogram indicate highest gust (ms^{-1}) as measured by a Dines Anemograph for all years 1949–83. (C) Frequency of wind direction (%) at 0900 h for all speeds (all years 1948–83).

Western Australia. The mean wind flow over the island is thus northwest to westerly. The circulation of the Southern Hemisphere is characterised by a semi-annual change of pressure gradient (and consequently of windspeed) between middle and high latitudes. This has been analysed by van Loon (1967) and attributed by him to different seasonal temperature trends in middle and high latitudes, and ultimately to different responses of the ocean heat balance at different latitudes and seasons. The annual cycle of mean sea-level pressure at Macquarie Island is shown in figure 3A and the semi-annual variation of pressure gradient averaged over a span of South Pacific longitudes in figure 3B.

The latter indicates, between 40°S and 60°S, larger pressure gradients and thus stronger winds in spring and autumn than in summer and winter. This general observation for the hemisphere is also apparent in data on mean surface windspeed (fig. 4A) and the frequency of gales for Macquarie Island (fig. 4B), as is the predominant west to northwest directional frequency throughout the year (fig. 4C). The extension of this flow throughout the troposphere is shown in the mean vector wind data at standard pressure levels for mid-season months at Macquarie Island in table 1.

The hemispheric westerly annulus is the domain of the great mid-latitude cyclones or depressions which form throughout the year as vortices within the westerly flow and whose associated frontal systems bring periods of severe weather to the southern parts of the Southern Hemisphere continents. In the Australasian region such weather systems most frequently form in the central to eastern South Indian Ocean sector and move generally to the east and southeast, controlled by the prevailing west to northwest flow in the upper air. The cyclones are readily identified in satellite imagery by their characteristic cloud vortices, an example of which is shown in plate 1, and data can be obtained on their evolution and track (Streten & Troup 1973, Carleton 1979). Analyses of mean track data derived from satellite and conventional observations (e.g. fig. 5) show the centres frequently passing close to the island. The gales, rain, snow and heavy seas associated with the passage of the depressions and associated frontal systems are characteristic of the Macquarie Island climate; on average, a front or depression centre probably passes the island once every five or six days. Such events are significant in the human history of Macquarie Island, which includes many shipwrecks, and tragedies due to severe weather.

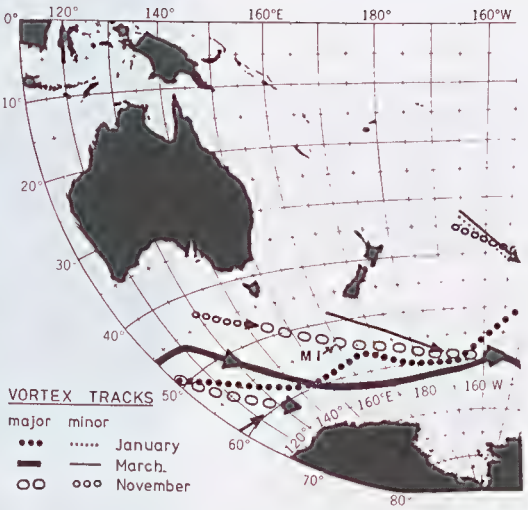


FIG. 5 — Vortex (depression) track diagram. Data from Streten & Troup (1973). MI indicates the position of Macquarie Island.

TABLE 1

Mean vector winds (degrees/ms^{-1}) — upper air, Macquarie Island

Available data 1953–83; number of observations approx. 750 for each month and level.

Pressure level (hPa)	Approx. ht (m)	January	April	July	October
900	850	283/11	282/14	283/10	280/14
850	1310	281/12	281/15	282/10	279/15
700	2830	279/14	280/17	278/12	277/17
500	5350	278/19	278/22	278/15	277/23
300	8860	280/24	279/27	276/17	276/28
200	11470	278/20	279/25	276/21	277/28
100	15930	284/10	282/18	275/29	277/26

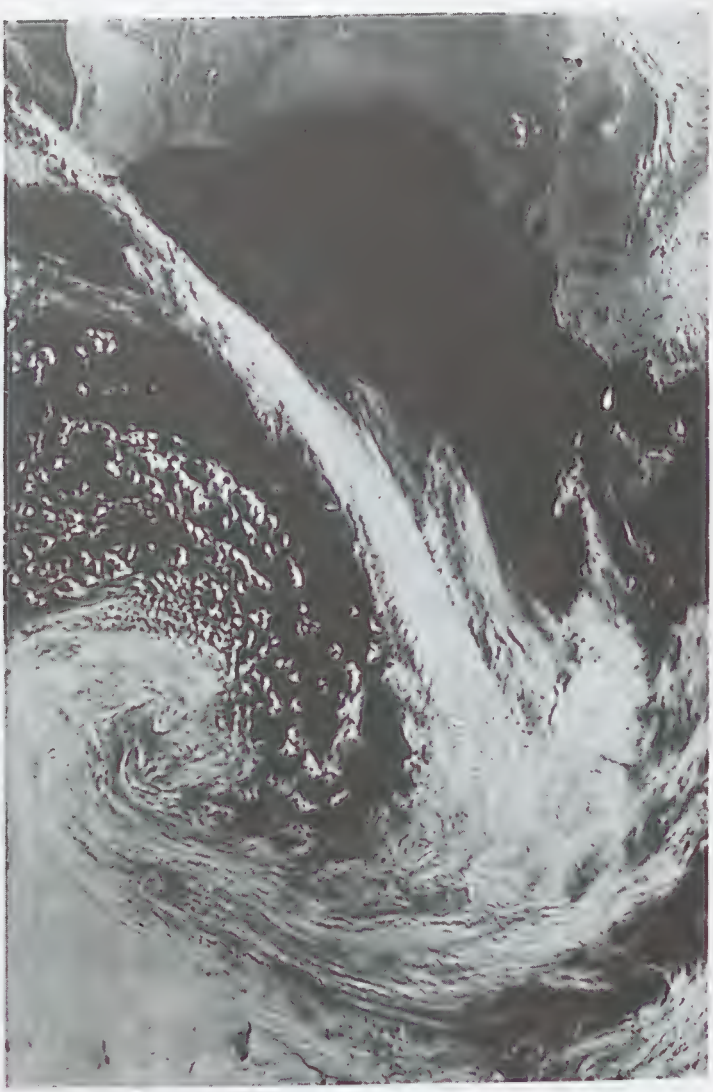
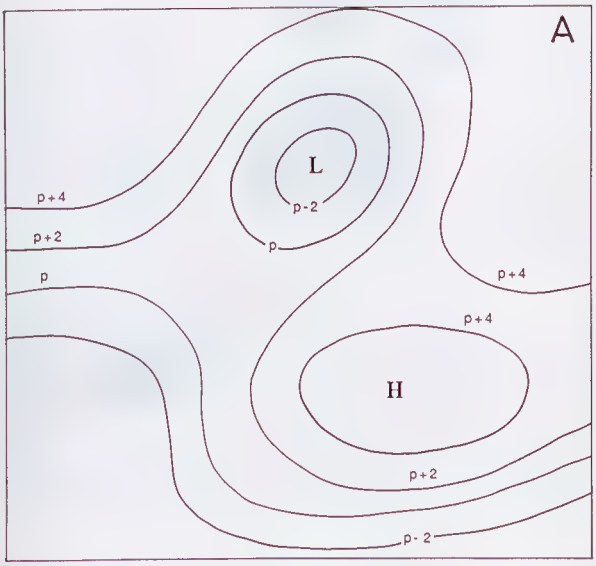


PLATE I
Satellite imagery of the Southern Ocean from a U.S. Defence satellite, showing depression vortex and frontal structure extending northwestward from the Macquarie Island region, with convective cloud activity to the west of the vortex centre.

For example, the Australian sealer Hasselborough, the first known visitor to the island in 1810, reported the finding of the wreckage of an old-fashioned ship on the shore, and the Commonwealth Fisheries ship *Endeavour* foundered with all hands after relieving the staff of the meteorological station in December 1914.

The 34 km elongated NNE-SSW ridge of the island (fig. 1B), rising generally to over 200 m and in parts to over 300 m above sea level, intercepts the wind flow from all directions. This results in local lee vortices, particularly in the region of Buckles Bay, where the topographic effects of the detached 100 m peak of Wireless Hill, the low-lying isthmus and the northern end of the main island ridge, result in variations in lee wind patterns in the prevailing general westerly flow, which often cause difficult conditions during ANARE ship-to-shore operations.

The longitude of Macquarie Island, which determines the small but significant northerly component observed in the general westerly flow, is also important in a further aspect of the broadscale atmospheric circulation, viz. the high frequency of



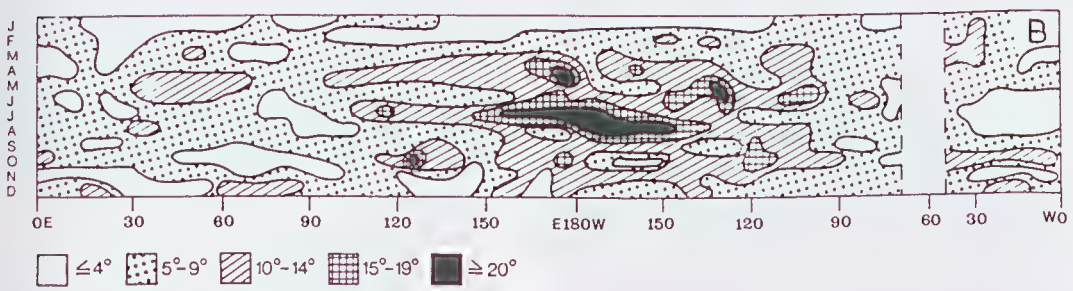


FIG. 6 — (A) Schematic pressure field associated with a blocking pattern (see text). (B) Annual pattern of the variability (degrees of latitude) of the mean monthly 1015 hPa isobar poleward of the subtropical axis of high pressure for the southern hemisphere; data for 1972–77 after Streten (1980).

so-called "blocking" phenomena which profoundly affect the weather of the southern Tasman Sea in general and that of Macquarie Island in particular. A classical blocking pattern is associated with a splitting of the upper westerly flow and the extension of high pressure into the higher latitude westerlies with lower pressure at low latitudes as shown in figure 6A. Observational studies such as those of Wright (1974) indicate that the southern Tasman Sea and adjacent regions experience a high frequency of blocking, particularly in winter. This is also revealed in data on the latitudinal range of an isobar of mean monthly pressure; e.g. figure 6B indicates the uniquely high variability of the circumpolar 1015 hPa isobar poleward of the axis of high pressure at the longitudes of the Tasman Sea and extending eastward of New Zealand. Blocking patterns in this region are important to the weather at Macquarie Island in disrupting the progression of depressions eastward in the westerlies and producing persisting high pressure to the east. This frequently results in prolonged periods of northerly flow which, by transferring moist warmer air from lower latitudes over the colder Southern Ocean, cause vast areas of fog over the waters surrounding the island. Fogs are also common in northerly air flow ahead of frontal changes, and are observed at Macquarie Island on average about 70 days each year, distributed fairly evenly in all months.

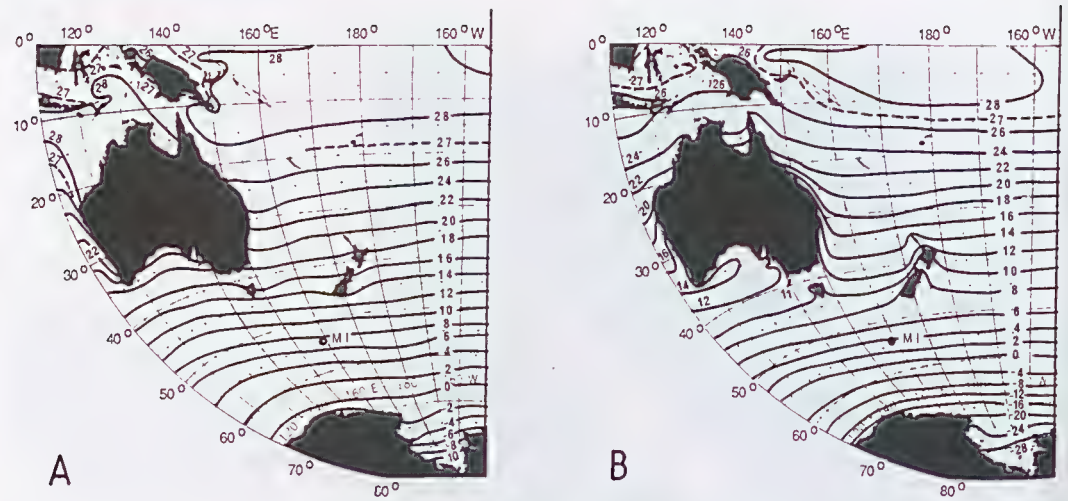


FIG. 7 — Surface mean air temperature (° C) for (A) January and (B) July. Data from Taljaard et al. *(1969). MI indicates the position of Macquarie Island.*

TEMPERATURE AND HUMIDITY

The patterns of surface mean air temperature over the region in January and July are shown in figure 7, the most notable features being the difference between conditions over the ice-free waters in January and the pack ice zone in the same area in July, when the ice edge lies only some 300 to 400 km south of the island (fig. 8).

The chief characteristics of Macquarie Island temperatures shown in figure 9 are the relatively small annual variation and the absence of very marked extremes. An analysis of mean seasonal temperatures typical of oceanic islands at these southern latitudes (Streten 1977b) indicates, as would be expected from their locations, that temperature conditions at Campbell Island, Kerguelen Island, Marion Island and the Falkland Islands (Stanley) are very similar to those at Macquarie Island, with mean summer temperatures at all locations lying between 5°C and 10°C and mean winter temperatures between 0°C and -5°C. However, island stations lying south of the Antarctic Convergence (though not necessarily south of Macquarie), e.g. Heard Island, experience much more severe temperatures. Figure 10 compares the interannual variability of mean seasonal temperature for higher Southern Hemisphere locations, and indicates that in winter this increases from middle to high latitudes over the oceans, reaching a maximum within the pack ice fringe. In summer, however, in the absence of the pack ice, all the islands experience a similar interannual variability.

The mean relative humidity experienced throughout the year at 0900 h local time is also shown in figure 9. The data are almost identical with those observed at 1500 h local time and are typical of those at oceanic islands in mid-latitudes. Because of the low temperatures, however, the absolute humidity (i.e. the actual amount of water vapour per unit volume of air) is always relatively low. Mean upper air temperatures at standard pressure levels for mid-season months are shown in table 2, with mean water vapour content expressed in terms of mixing ratio (grams of water vapour per kilogram of air).

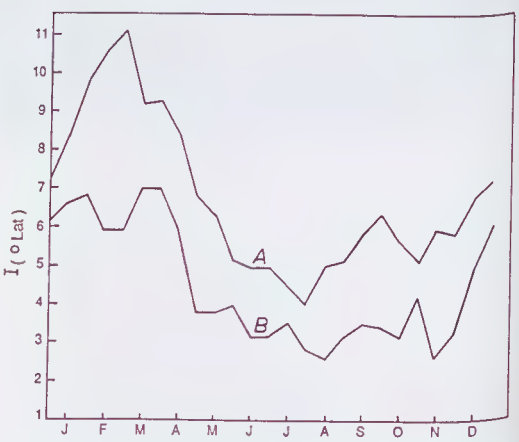


FIG. 8 — Separation of Macquarie Island from the pack ice edge I (degrees of latitude) at 159° E. (A) mean, (B) minimum. Data for period 1973–82 from Naval Oceanography Command (1985).

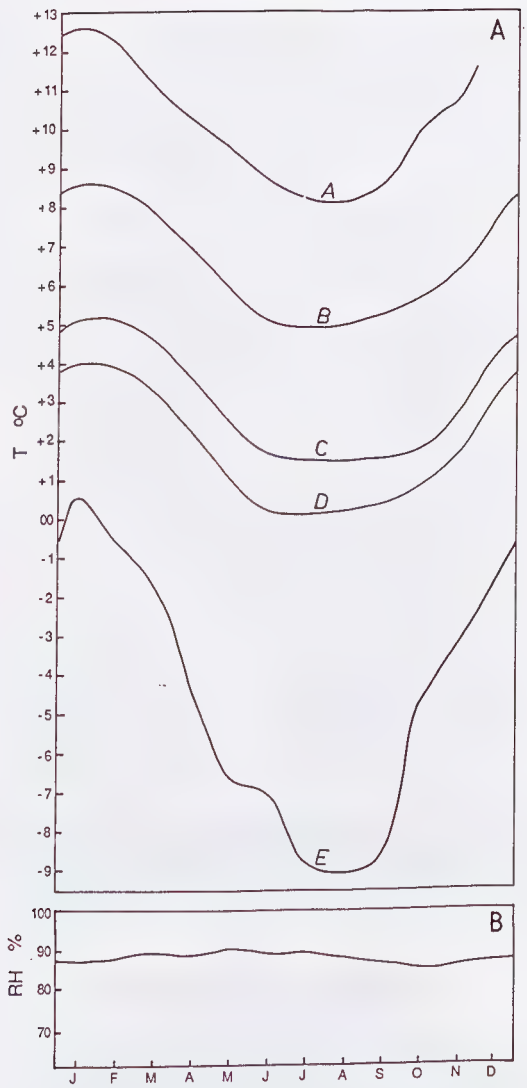


FIG. 9 — (A) Temperature data for Macquarie Island — A, extreme daily maximum; B, mean daily maximum; C, mean daily minimum; D, extreme daily minimum; E, mean terrestrial minimum (all available data, 1948–83). (B) Mean relative humidity (%) at 0900 h (all available data 1948–83).

TABLE 2

Mean upper air temperatures (°C) and mixing ratios (gr/kg), Macquarie Island

Available data 1950–82, total number of observations approx. 750 for each month and level.

Pressure level (hPa)	Approx. ht (m)	January	April	July	October
900	850	1.3 (3.5)	0.2 (3.2)	-2.1 (2.8)	-2.0 (2.7)
850	1310	-0.5 (3.0)	-1.9 (2.6)	-4.1 (2.2)	-4.3 (2.1)
700	2830	-7.2 (1.4)	-9.1 (1.2)	-11.7 (0.8)	-11.6 (0.9)
500	5350	-22.2 (0.5)	-24.7 (0.4)	-28.9 (0.2)	-27.3 (0.3)
300	8860	-46.1 (*)	-49.1 (*)	-55.0 (*)	-50.5 (*)
200	11470	-49.3 (*)	-54.3 (*)	-60.9 (*)	-52.5 (*)
100	15930	-49.1 (*)	-53.5 (*)	-58.2 (*)	-48.9 (*)

* = <0.1

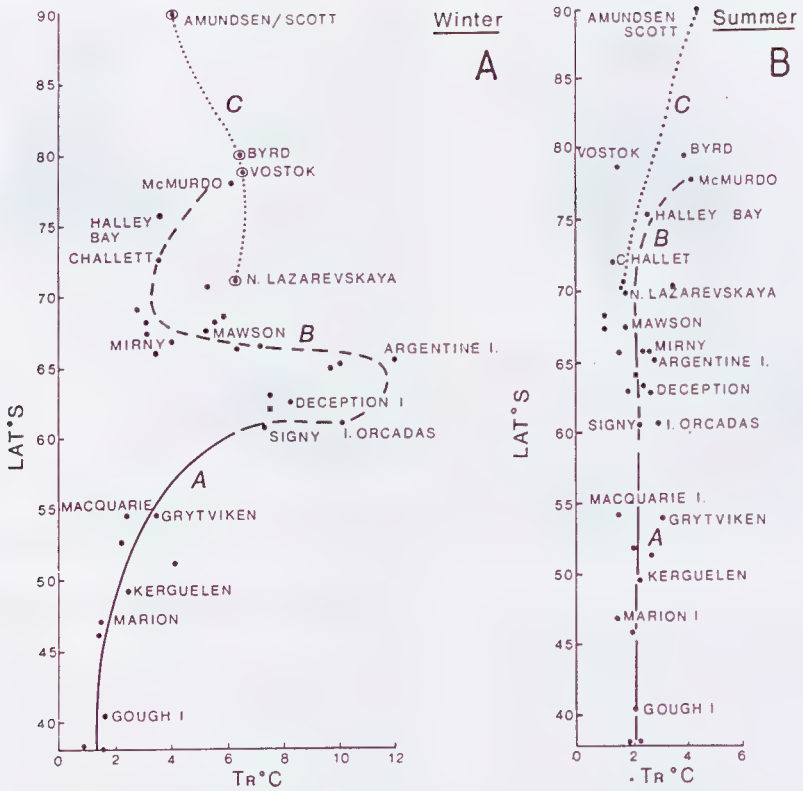


FIG. 10 — Latitudinal variation in the range of the mean seasonal temperature (T_R) for high latitude stations in (A) winter (June to September) and (B) summer (December to March). A — the southern oceans; B — the pack ice zone and coastal Antarctica; C — continental Antarctica (after Streten 1977a).

SUNSHINE, CLOUD AND PRECIPITATION

The generally low mean temperatures throughout the year are accompanied by a cloud cover averaging seven-eighths in all months, with the low mean hours of sunshine shown in table 3. Cloud is generally low stratiform, typical of middle to high southern oceanic latitudes, frontal discontinuities being marked by passage of a zone of cloud of greater depth and substantial convective activity, but rarely with thunder. To the rear of a typical cold front (see plate 1) scattered convective cloud occurs as colder, higher-latitude air is destabilised over the relatively warmer water; however, the more typical stratiform pattern is soon re-established.

The island ridge lying across the flow of the westerlies ensures a high frequency of days on which precipitation occurs. This varies little in the

TABLE 3

Mean daily hours of sunshine — Macquarie Island

Available data 1948–53 and 1965–83.

Month	J	F	M	A	M	J	J	A	S	O	N	D
hours	3.4	3.5	2.6	1.7	1.1	0.6	0.8	1.4	2.0	2.7	3.3	3.2

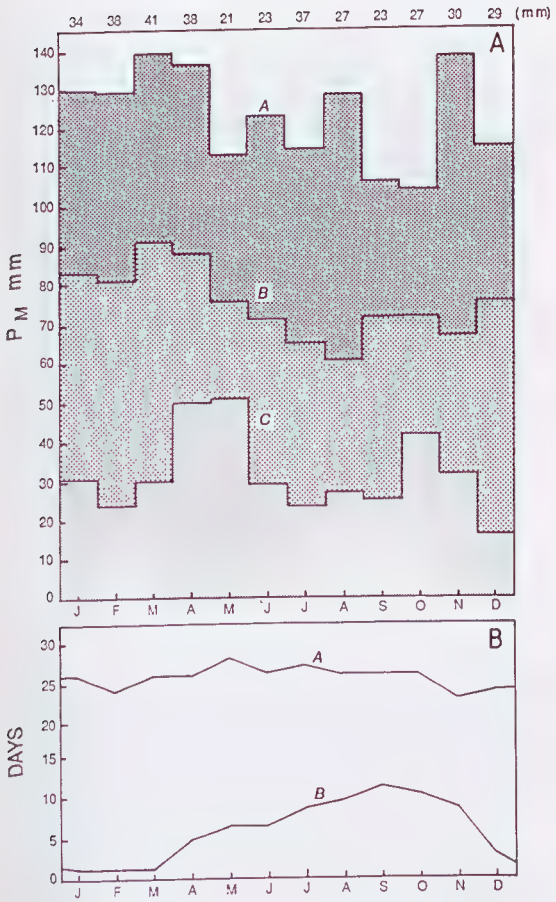


FIG. 11 — Precipitation data for Macquarie Island. (A) Monthly total (P_M). A — maximum; B *— mean;* C *— minimum; figures above the diagram show the highest observed 24-hour precipitation (mm) (all available data 1948–83). (B) Mean number of days per month with A — precipitation >0.1 mm (all available data 1948–83);* B *— observed snowfall (data 1967–83).*

mean from month to month throughout the year (fig. 11B) and totals some 308 days annually. Snowfall occurs throughout the year, with a maximum frequency in spring. Monthly precipitation amounts shown in figure 11(a) also vary little from month to month, with an annual average over 32 years of 901 mm. This amount is compared, in figure 12, with that observed at other Southern Ocean islands, and indicates the general decrease in annual precipitation with increasing latitude (and lower temperature and absolute humidity).

The upper levels of the plateau of Macquarie Island are covered with wet snow for much of the year, particularly from May to October, and depths in level areas may reach 0.5 to 1.0 m at the end of the season (P. Ruckert, pers. comm.).

MACQUARIE ISLAND AS AN OBSERVATION STATION

Although the earlier observations from the 1911–14 period were recognised as valuable for weather forecasting for southern Australia and New Zealand, it was only with the introduction of Northern Hemisphere concepts of frontal analysis to the Australasian region in the 1930's and 1940's (initially by E. Kidson in New Zealand — see Kidson & Holmboe 1935) that the full utilisation of observations from isolated stations such as Macquarie Island became possible. Initially, such studies were carried out retrospectively (Kidson 1947), but with the establishment of a number of stations reporting regularly several times a day by radio (including the ANARE bases at Macquarie Island and Heard Island) in the late 1940's, attempts began at coherent operational meteorological analysis for large sectors of the Southern Ocean. In Australia, such work was pursued in the Bureau of Meteorology offices in Melbourne and Hobart (e.g. Gibbs *et al.* 1952, Langford 1957, 1960); this complemented the very extensive studies being carried out by J.J. Taljaard and H. van Loon at the South African Weather Bureau and those at the Massachusetts Institute of Technology in the early

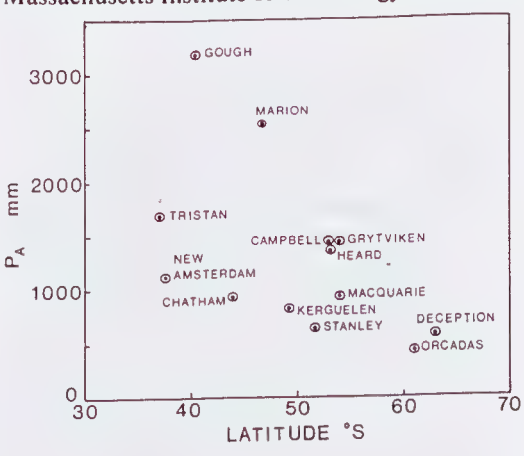


FIG. 12 — Long-term mean annual precipitation P_A (mm) as a function of latitude for Southern Hemisphere islands (data from Streten 1977b).

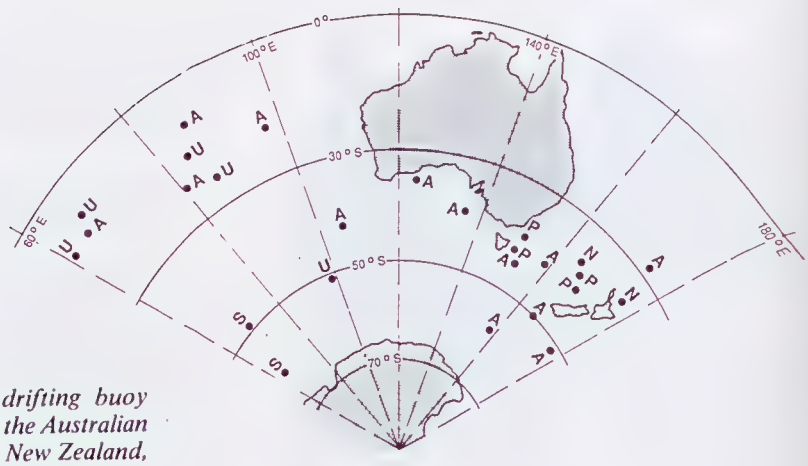


FIG. 13 — International drifting buoy network in December 1986 in the Australian region. A — Australia, N — New Zealand, S — South Africa, U — United States, P —other.

1950's. Macquarie Island data were recognised, particularly in Hobart, as being of great value for forecasting for southeastern Australia. The orientation of frontal systems moving eastward in the westerlies was frequently such that they passed the island some hours before their northern extremities affected south and west Tasmania; thus, monitoring changes at Macquarie together with pressure changes over southern Australia and Tasmania often provided useful (and indeed, the only) clues for the forecasting of the arrival of major weather changes.

By the late 1950's, the network of fixed stations in the Southern Ocean and Antarctica had almost reached its present state, following the impetus of the International Geophysical Year (IGY) of 1957–58. By the mid-1960's, global satellite data were becoming increasingly available and, together with new numerical analysis methods, revolutionised the study of meteorology of the Southern Hemisphere (e.g. review by Streten & Zillman 1984). Initially, visual and infra-red imagery was used and examined in relation to existing observations; e.g. Zillman & Martin (1968) give an analysis of a frontal passage at Macquarie Island using conventional and satellite observations. By the mid-1970's, satellite technology had developed to the stage of measuring vertical temperature profiles closely paralleling the main features of those derived from radiosondes, and, during the First (Global Atmospheric Research Program) Global Experiment (FGGE) of 1978–79, an international fleet of satellite-reporting drifting buoys was deployed on the Southern Ocean. These provided a limited surface pressure network and "ground truth" observations necessary for the derivation of the upper air temperature profiles from the satellite data. The demonstration of the value of the buoys during FGGE has led to a gradual re-establishment of the internationally funded drifting buoy network, and figure 13 shows an example of the operational data currently available on a day-to-day basis.

With such developments the unique value to synoptic analysis of the individual ocean stations, such as Macquarie Island, has diminished but not disappeared. Representative and accurate observations from various ocean sites are still required to calibrate the global satellite data, and Macquarie Island has recently been selected by the World Meterological Organization (WMO) as one such baseline station. Its regular observations programme (see table 4) provides a long-term record of climate at a fixed site.

As indicated in figure 1 almost all suitable islands of the Southern Ocean have now been utilised as observing points in the WMO concept of the World Weather Watch (WWW). Australia plays its part in this programme over the Southern Ocean by maintaining the surface and upper air observation station at Macquarie Island and an unmanned Automatic Weather Station (AWS) on Heard Island, in providing buoys to the international fleet and in making the derived data

available on the Global Telecommunications System (GTS) for global analysis and research. It is only such international co-operation in providing free exchange of data that makes operational meteorology possible. Wealthier countries, such as the USA, USSR, Japan and the European Community, provide complex and costly satellite systems for global observation of some parameters, while smaller nations contribute conventional station data from their territories. Thus, no part of the WWW system can entirely dispense with another in present-day operational meteorology, where a continuing three-dimensional global data coverage is essential to provide data for the complex numerical models now used in weather forecasting.

MACQUARIE ISLAND AS A MONITORING STATION FOR BROADSCALE CLIMATIC INDICATORS, ATMOSPHERIC CONSTITUENTS AND CLIMATE CHANGE

Over recent years, both scientific literature and the popular press have shown an increasing interest in possible gross changes to the earth's climate system and in potential strategies to alleviate natural changes and prevent those which might be caused by the actions of man. In all such investigations, an accurate and sufficiently long data record from geographical locations well-spaced across the globe is essential. Long-term observations from such stations as Macquarie Island, which, unlike many on the continents, are unaffected by increasing urbanisation, local industrial activity, vegetation change or major alterations

TABLE 4

Observation programme on Macquarie Island in 1986

Type of observation	Daily observation times (GMT)	Continuous record
SURFACE:		
Temperature	0200, 0500, 0800, 1100 1400, 1700, 2000, 2300	yes
Pressure	"	yes
Wind direction	"	yes
Wind speed	"	yes
Visibility, cloud cover	"	no
Humidity	"	yes
Precipitation	"	yes
Sunshine hours	Daily total	yes
Wind run	2300	no
UPPER AIR:		
Winds	0500, 1100, 1700, 2300	no
Pressure, temperature and humidity	1100, 2300	no
OZONE:		
Total content	Measured 3 times a day during winter, 5 times a day other seasons	no
Vertical distribution	At least twice a month	no
RADIATION:		
Global	Half-hourly intervals	yes
Diffuse	"	yes
TRACE GAS ANALYSIS:		
Carbon dioxide	2–4 samples per month; sampling duration 8 hours and 24 hours	no

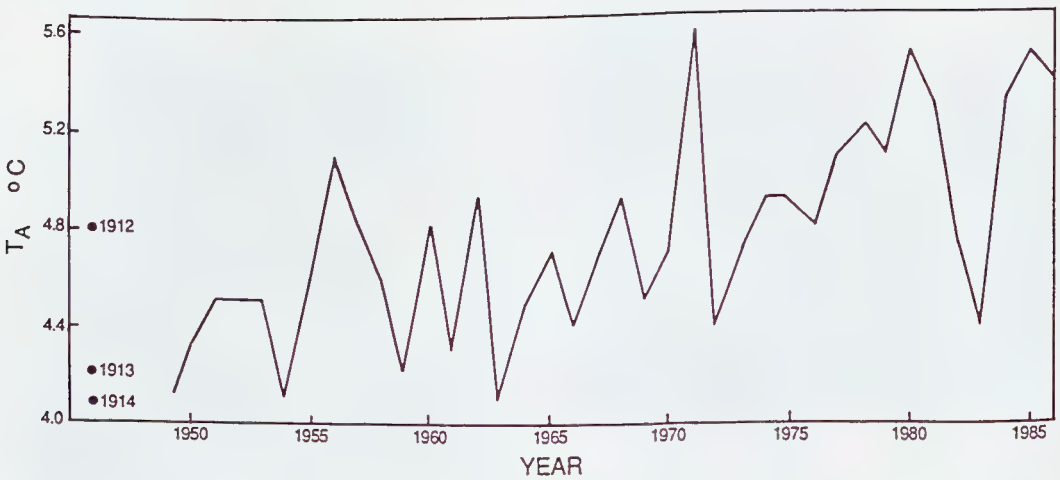


FIG. 14 — Mean annual temperature T_A = ½ (mean annual max. + mean annual min.) for Macquarie Island. Points for 1912, 1913, 1914 are calculated from data given by Kidson (1946).

to the local site characteristics, are particularly valuable in monitoring the possible long-term trends in the climate record. This is particularly so in higher latitude regions, where some of the possible changes may be earlier and more readily detectable, e.g. global atmospheric warming resulting from increased CO_2 and other greenhouse gases. Our ability to assess the reality of some of the proposed mechanisms, trends and climate modelling results depends on a very careful analysis of all the characteristics of the record at many locations. Such analyses are not always performed with a cognisance of the natural variability and the complexities involved, e.g. some views that have been advanced over the past 15 years are:

(1) A belief that a global cooling had commenced, consistent with apparent sudden climatic changes observed in some proxy records of past climate and with the statistical evaluation that the present interglacial period should be drawing to an end. The observational evidence advanced was some years of satellite-derived data, which showed an apparently increasing seasonal snow cover over the Northern Hemisphere continents. The trend, however, soon reversed; more accurate data now available show the areal snow cover exhibiting yearly fluctuations around a mean with no continuous increase.

(2) A belief that global warming had commenced, based on the satellite observation of a decline in antarctic sea ice extent for the first five years that such data were available. Again, the trend reversed; present observations show fluctuations in particular sectors at different times but no persisting decrease.

(3) A belief that global warming has been progressing for at least a century, following from the increased industrial emission of CO_2 and other greenhouse gases. Numerous manipulations of existing long-term temperature data have been made with various results; many are inconclusive, but the most recent (Jones *et al.* 1986) indicates a probable mean Southern Hemisphere rise of 0.5°C over the past century. This assessment does not show the cooling trend between 1938 and 1965 which is apparent in the overall warming of the Northern Hemisphere over the past century. However, the representativeness and accuracy of much of the data, particularly over the Southern Hemisphere oceans is still questionable. The Macquarie Island data (fig. 14) show an apparent slight upward trend in mean temperature since 1949 but the significance of such data must be considered in the light of many other observations at other locations.

The fact of the atmospheric CO_2 steadily increasing during the period of accurate observation since the 1950's, and probably (though less well documented) since the last century, is the one item of data which supports the possibility of an anthropogenetically induced climate warming. However, the basic quantitative global data and time coefficients of the carbon cycle in the atmosphere and oceans (particularly the Southern Ocean) are not accurately known. Experiments with numerical models, however, indicate various results, depending on the characteristics of the model and the inclusion or exclusion of particular physical processes, such as the ocean effects and cloud characteristics. The most reliable appear to

project an increased global temperature of 3°C ± 1.5°C with a doubling of CO_2 which, if present rates continue, might occur within 50 to 100 years.

Similarly, the recent discovery of the recurring springtime O_3 "hole" over Antarctica over a number of years has raised questions of its origin and the chemical and dynamical processes at work; these are as yet unresolved but possible ramifications continue to excite widespread, but not always considered comment.

In all such data studies, modelling and public debate, a cautionary note must be sounded. Short-term trend observations of some quantities proved to be delusive in providing evidence of some theories of global climate change that otherwise appeared to have a not-unreasonable theoretical basis. Similarly, the duration of observational record in relation to the complex chemical and physical processes which may be occurring in the atmosphere and ocean, with CO_2, O_3, and the other greenhouse gases, needs to be considered; it may not always be obvious what time spans in observed fluctuations are important. Thus, measurement of O_3 has been progressing for over 30 years at Macquarie Island; these data are now being re-evaluated in the light of the recent observations in the antarctic which raise the possibility of an extension of the "hole" to lower latitudes. The importance of long-term records has been stressed at some length, because such an "observatory" activity is often unpalatable to many short-term scientific investigators and always to those meeting the cost of a programme continuing over many decades.

CONCLUSION

An outline of the principal climatic elements of Macquarie Island has been given. The value of the observational data is apparent for the study of the great wealth of biological activity on the island, for the day-to-day analysis of hemispheric weather and for the long-term monitoring of possible climate change in a sensitive area of the atmosphere-ocean system.

ACKNOWLEDGEMENTS

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REFERENCES

ANARE, 1948–68: *Australian National Antarctic Research Expeditions Reports*, Ser. D, Meteorology (I–XXI). Antarctic Division, Melbourne.

CARLETON, A.M., 1979: A synoptic climatology of satellite observed extratropical cyclone activity for the southern hemisphere winter. *Arch. Met. Geophys. Bioklim.*, B27: 265–279.

GIBBS, W.J., GOTLEY, A.V. & MARTIN, A.R., 1952: Meteorology of Heard and Macquarie Islands 1948; part IC — Discussion. *ANARE Rep.*, Ser. D(I). Antarctic Division, Department of External Affairs, Melbourne.

JENNE, R.L., CRUTCHER, H.L., VAN LOON, H. & TALJAARD, J.J., 1971: *CLIMATE OF THE UPPER AIR, SOUTHERN HEMISPHERE: IV.* NAVAIR 50-IC-57. U.S. Navy, Washington, D.C.

JONES, P.D., RAPER, C.B. & WIGLEY, T.M.L., 1986: Southern hemisphere surface air temperature variation 1851–1984. *J. Clim. Appd Met.*, 25: 1213–1230.

KIDSON, E., 1946: Discussion of observations at Adelie Land, Queen Mary Land and Macquarie Island. *Australasian Antarctic Expedition 1911–1914 (AAE), Sci. Rep.*, Ser. B(VI). Government Printing Office, Sydney.

KIDSON, E., 1947: Daily weather charts extending from Australia and New Zealand to the Antarctic continent. *AAE Sci. Rep.*, Ser. B(VII). Government Printing Office, Sydney.

KIDSON, E. & HOLMBOE, J., 1935: *FRONTAL METHODS OF WEATHER ANALYSIS APPLIED TO AUSTRALIA-NEW ZEALAND AREA:* Part I — Discussion, Part II —Weather Charts. N.Z. Department of Science and Industrial Research Meteorological Bureau, Wellington.

LANGFORD, J.C., 1957: Southern Ocean analysis with special reference to the period December 1954 to March 1955. *Aust. Met. Mag.*, 15: 1–22.

LANGFORD, J.C., 1960: Aspects of the circulation and analysis of the Southern Ocean. *In ANTARCTIC METEOROLOGY.* Pergamon, Oxford: 256–273.

NAVAL OCEANOGRAPHY COMMAND, 1985: *SEA ICE ATLAS:* I, Antarctic. NAVAIR 50-IC-540 NSFL MS 39524-500. U.S. Navy, Washington, D.C.

NEWMAN, B.W., 1929: Tabulated and reduced records of the Macquarie Island station. *AAE Sci. Rep.*, Ser. B(III). Government Printing Office, Sydney.

STRETEN, N.A., 1977a: Aspects of the year to year variation of seasonal and monthly mean station temperature over the southern hemisphere. *Mon. Wea. Rev.*, 105: 195–206.

STRETEN, N.A., 1977b: Seasonal climatic variability over the southern oceans. *Arch. Met. Geophys. Bioklim.*, B25: 1–19.

STRETEN, N.A., 1980: Some synoptic indices of the southern hemisphere mean sea level circulation 1972–1977. *Mon. Wea. Rev.*, 108: 18–36.

STRETEN, N.A. & TROUP, A.J., 1973: A synoptic climatology of satellite observed cloud vortices over the southern hemisphere. *Quar. J. R. Met. Soc.*, 99: 56–72.

STRETEN, N.A. & ZILLMAN, J.W., 1984: Climate of the South Pacific Ocean. *In* H. van Loon (Ed.): *CLIMATES OF THE OCEANS.* Elsevier, Amsterdam: 263–429.

TALJAARD, J.J., VAN LOON, H., CRUTCHER, H.L. & JENNE, R.L., 1969: *CLIMATE OF THE UPPER AIR–SOUTHERN HEMISPHERE.* NAVAIR 50-IC-55. U.S. Navy, Washington, D.C.

VAN LOON, H., 1967: The half yearly oscillations in middle and high southern latitudes and the coreless winter. *J. Atmos. Sci.*, 24: 472–486.

WRIGHT, A.D.F., 1974: Blocking action in the Australian region. *Bur. Met. Melbourne, Tech. Rep.* 10.

ZILLMAN, J.W. & MARTIN, D.W., 1968: A sharp cold frontal passage at Macquarie Island in the southern ocean. *J. Appl. Met.*, 7: 708–711.

(accepted 30 June 1987)

AN ANALYSIS OF AIR TEMPERATURE RECORDS FOR MACQUARIE ISLAND: DECADAL WARMING, ENSO COOLING AND SOUTHERN HEMISPHERE CIRCULATION PATTERNS

by D.A. Adamson, P. Whetton and P.M. Selkirk

(with five text-figures)

ADAMSON, D.A., WHETTON, P. & SELKIRK, P.M., 1988 (viii): An analysis of air temperature records for Macquarie Island: decadal warming, ENSO cooling and Southern Hemisphere circulation patterns. *Pap. Proc. R. Soc. Tasm.*, 122(1): 107–112. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. School of Biological Sciences and Quaternary Research Unit, Macquarie University, Sydney, Australia 2109; and Department of Geography, Monash University, Clayton, Australia 3168.

Macquarie Island lies close to, but on the eastern side of the boundary between the eastern (Pacific) and western (India–Australia) limbs of the Southern Oscillation. Its temperature record matches that of the area east and southeast of New Zealand, rather than Tasmania. Temperature is influenced by atmospheric pressures in the Southern Ocean to the east and west, which can result in a warm northeasterly or cold southerly airflow over the island. It is a sensitive indicator of climatic trends because of its location at high latitude in a longitudinal region of frequent ridge formation and blocking in the Southern Hemisphere circulation.

Temperature records for Macquarie Island (1949–86) show a 1°C warming trend (twice the global average), accelerating in the last 20 years with eight of the ten warmest years occurring in the last decade. The greatest average rate of warming has occurred in late summer and early autumn and the lowest in spring. In severe ENSO years the island cools. The warming is marked, in relation to the annual mean (4.8° C), and the biological effects should be considered.
Key Words: atmospheric change, climatic warming, Southern Oscillation (SO), El Nino–Southern Oscillation (ENSO), Macquarie Island.

INTRODUCTION

The world has warmed by about 0.5°C over both land and ocean during this century, the Southern Hemisphere showing a more regular increase than the Northern (Folland *et al.* 1984, Jones *et al.* 1986). High latitudes in the Northern Hemisphere show amplified temperature changes compared to lower latitudes (Kelly *et al.* 1982, Raper *et al.* 1983), in conformity with theoretical predictions (Polar Review Group 1980). In the Southern Hemisphere, Jacka *et al.* (1984) noted a warming trend which was more pronounced at higher latitudes. North of Macquarie Island, Salinger & Gunn (1975) showed that New Zealand warmed markedly from about 1935 to 1970, a period when cooling interrupted the longer-term warming trend in the Northern Hemisphere.

Climatic data are scarce in the Southern Hemisphere south of about 45° S (Salinger & Gunn 1975, Jones *et al.* 1986). Macquarie Island (54° 30′S, 158° 56′E), one of the few sites suitable for supplying such information, has the additional advantage that it lies southeast of the Australian continent, where the westerly circulating Southern Ocean and atmosphere impinge upon the southwestern Pacific Ocean. Van Loon & Shea (1987) point out the interest of this region because of its possible involvement in the Southern Oscillation (SO).

The present paper analyses the marked warming that has been recorded on Macquarie Island, at the meteorological station situated 6 m above sea level near the northern end of the island. The regional meteorological context and links to SO are also considered. Sources of data are Jacka *et al.* (1984), supplemented by meteorological records held on the island.

TEMPERATURE TRENDS

Macquarie Island mean annual surface temperature shows a marked upward trend of about 1°C since annual records commenced in 1949 (fig. 1). Eight of the ten warmest years have occurred during the past decade, whereas none occurred during the first 19 years of the record. Warming has occurred in all months (fig. 2), with the largest rise in monthly mean (0.042°C per

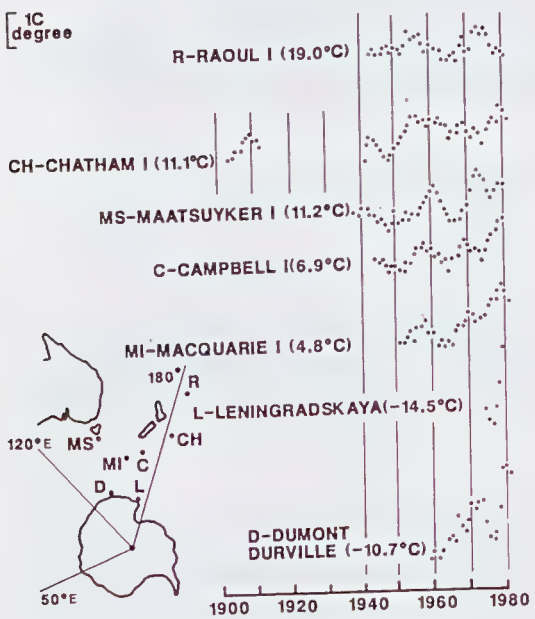

FIG. 1 — Five-year running means of annual mean temperature (mean for whole record in brackets) at stations in the region east and south of New Zealand and eastern Australia.

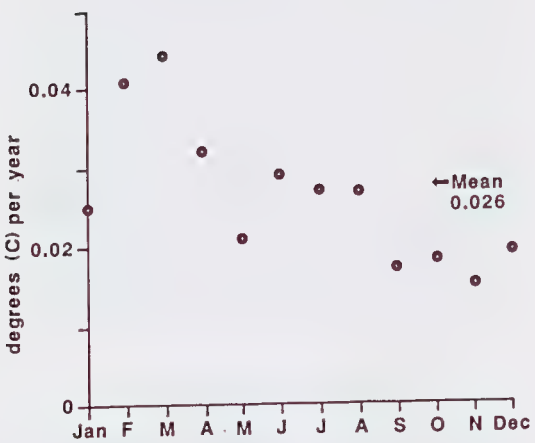

FIG. 2 — The rate of temperature increase at Macquarie Island month by month over 38 years from 1949 to 1986. The mean rate for all months is shown.

annum) occurring in late summer and early autumn and the smallest (0.018°C per annum) in spring. The shape of the seasonal cycle in rate of warming is opposite to that of the latitudes of both the mean northern limit of antarctic sea ice (Jacka 1983) and the subtropical high-pressure zone (Pittock 1971). In effect, the rate of warming on Macquarie Island is greatest when the sea ice is furthest away and the mid-latitude high-pressure zone is closest, presumably because of the increased probability of warm northern air penetrating southward to the island.

REGIONAL TEMPERATURE AND PRESSURE CONTEXT

Figure 1 shows temperature trends at stations near the longitude of Macquarie Island. With the exception of Raoul Island at 19° 15'S, they show a warming trend that becomes more obvious southwards. The temperature records for Macquarie and Campbell Islands are remarkably similar in their patterns of warmer and cooler periods, with Chatham Island somewhat less so. Maatsuyker Island shows a different pattern. The graphs of five-year running means of annual temperature suggest that the Macquarie Island trends are more closely linked to the region southeast and east of New Zealand than to Tasmania.

The regional affinities of the climate of Macquarie Island are shown by several studies of Southern Hemisphere atmospheric pressure. Berlage (1957) correlated monthly surface pressure at stations around the world with that at Djakarta to show the extent of SO, the fluctuation in pressure between an eastern area, centred on the central and eastern south Pacific, and a western area, centred on the Australian–Indonesian–Indian Ocean region. In his analysis, the Southern Ocean southeast of New Zealand is part of the eastern limb, whereas Tasmania and part of the Southern Ocean south of Australia lie within the western limb of SO. Macquarie Island lies near the boundary between these two vast areas of opposite pressure anomalies. Numerous, more recent analyses confirm a major boundary in the global circulation in the general region of Macquarie Island, with a tendency for the island to lie just within the eastern limb of SO (Trenberth 1976, van Loon & Madden 1981, Pan & Oort 1983, van Loon & Shea 1985, 1987, Gordon 1986).

Figure 3 shows the correlation between anomalies of monthly mean sea-level atmospheric pressure throughout the Australian–New Zealand

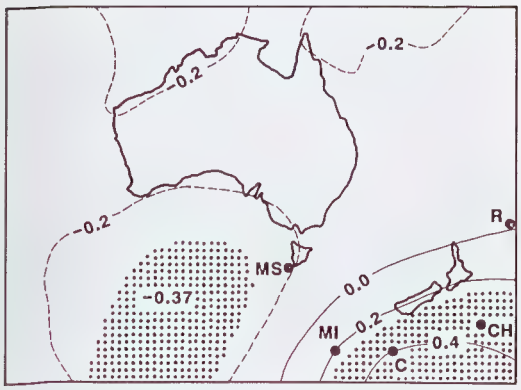

FIG. 3 — Correlation map of Macquarie Island detrended monthly mean temperature anomalies and monthly mean sea-level atmospheric pressure anomalies in the Australia–New Zealand region. The period analysed was 1970–80 (132 months). The shaded area shows correlation significant at the 1% level, allowing for reduction in the number of data points due to persistence. The meteorological stations shown on figure 1 are indicated.

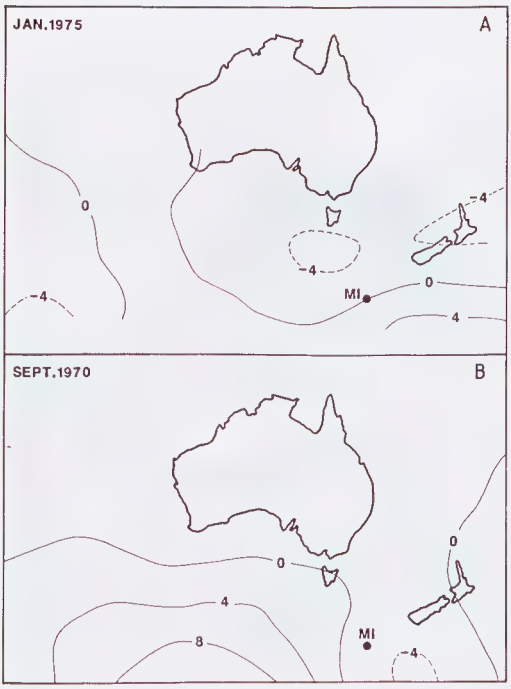

FIG. 4 — (A) Mean sea-level atmospheric pressure anomalies (mb) for January 1975 when the largest monthly positive temperature anomaly (+1.9° C) occurred at Macquarie Island (MI). (B) Mean sea-level atmospheric pressure anomalies (mb) for September 1970 when the largest monthly negative temperature anomaly (–1.3° C) occurred at Macquarie Island (MI).

region and temperature on Macquarie Island. For this analysis the long-term warming trend shown on Macquarie Island was removed. The map shows clearly the opposite behaviour of the Southern Ocean to the east and to the west of the island, and the affinity of Macquarie Island with the region east and southeast of New Zealand. The correlation map can be interpreted as showing an effect of wind direction on temperature. When the atmospheric pressure is high to the east of Macquarie Island (positive anomalies) and low to the west (negative anomalies), the wind direction in the Macquarie–Campbell region reflects the anticyclonic conditions and is more northeasterly than usual, thereby bringing warmer northern air southwards. Ridge formation and blocking over the Tasman Sea–New Zealand region (Wright 1974, Ramaswamy & Pareek 1978, Pierrehumbert *et al.* 1984, Trenberth & Mo 1985) may also direct warm northern air southwards to Macquarie Island. Invasion by northern air from New Zealand and Australia is an obvious means of long-distance dispersal for organisms. For example, the redpoll probably arrived from New Zealand on winds associated with high pressure to the east of the island. Organisms will no doubt continue to arrive on Macquarie Island by natural wind dispersal. By contrast, when there is anomalously high pressure south of Australia and low pressure southeast of New Zealand, cold southern air flows from the southwest over Macquarie Island.

Figure 4 shows the monthly mean pressure anomalies for two months during which extreme high and extreme low temperatures respectively occurred on Macquarie Island. These months illustrate the generalised picture shown in the correlation map (fig. 3). In January 1975, record high temperatures for the month were recorded on Macquarie Island (9.1° C) and on Campbell Island (11.0° C); Chatham Island was also unusually warm. As expected from figure 3, anticyclonic conditions east of Macquarie Island and southeast of New Zealand directed warm northern air over the island; similar conditions applied to Campbell and Chatham Islands. A contrary situation applied in 1970, when record lowest September temperatures were recorded for Macquarie Island (2.2° C, equal to that in 1954) and Campbell Island (4.3° C). Low

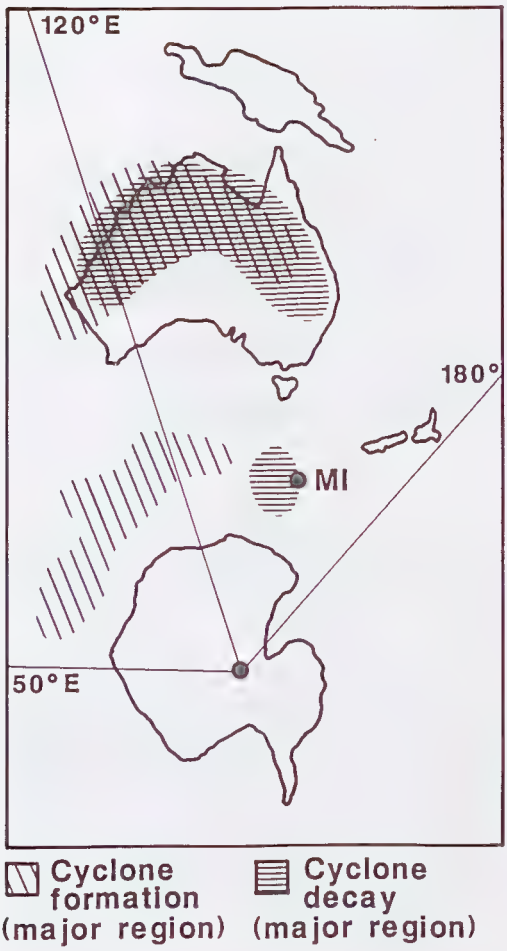

FIG. 5 — Locations of cyclone formation and decay in the Australia–New Zealand–Southern Ocean region. MI — Macquarie Island. Modified from Kep (1984).

pressure to the east and high pressure to the west of Macquarie Island directed cold southern air northwards over these two islands. However, Chatham Island was warmer than average, being under the influence of persistent northerly flow.

The contrast between the Macquarie Island region of the Southern Ocean and similar latitudes to the west is also shown in figure 5. Macquarie Island is in an area of cyclone decay. Few cyclones form there or to the east, but to the west lies one of the most intense areas of cyclone formation in the Southern Ocean (Rice 1982, Kep 1984). The area of intense cyclogenesis lies south of the Indian Ocean and western Australia where the largest waves in the Southern Ocean are generated. To the south of this region, Deacon (1984) noted recent retreat of the northern limit of summer sea ice around Antarctica. Examination of the data compiled by Jacka (1983) for the period 1973–83 shows a southwards retreat of sea ice in February by 2° to 4° latitude in the sector of the coast from about 50°E (Enderby Land) to about 180° to 160°W (Ross Sea). By contrast, minor retreat occurred south of the Pacific Ocean and none in the sector from the Atlantic Ocean to south of Madagascar.

EFFECT OF THE SOUTHERN OSCILLATION

Consequences of the SO seesaw in atmospheric pressure, sea-surface temperature and rainfall extend far beyond the tropics and subtropics of the region extending from India to the Americas. Influences can also be recognised or inferred around the globe at middle and high latitudes in both hemispheres (Ramaswamy & Pareek 1978, Chen 1982, Harnack & Harnack 1985, Raman & Maliekal 1985, Hense 1986, Peng & Domros 1987, van Loon & Shea 1987, Wolter 1987).

Echoes of SO appear in the Macquarie Island temperature record. The two most severe negative excursions of the SO index during this period occurred in 1972–73 and 1982–83 and corresponded closely with periods when the island was notably cold. Another period of severe cold in 1963 matched a period of negative SO index. During periods of negative index, which are called El Nino–Southern Oscillation (ENSO) events, high pressure anomalies, droughts and weak monsoons occur over the Australian–Indonesian–Indian region, while the opposite conditions occur over the central and eastern Pacific. As previously noted, Macquarie Island lies near, but to the east of the boundary between these two huge regions. High pressure anomalies to the west of Macquarie Island and negative ones to the east (figs 3 & 4) favour cold southerly circulation over the island and lead to negative temperature anomalies during severe ENSO events. Over New Zealand, Trenberth (1975) noted a switch to persistently cold southwesterly air flow in the severe ENSO year of 1972. Of course, other parts of the globe behave differently; for example, Northern Hemisphere land between 0° and 25°N warms during ENSO events (Bradley *et al.* 1987). Possibly the marked cooling on Macquarie Island and the associated pressure

anomalies during severe ENSO events are both related to a globally stronger meridional circulation at such times.

DISCUSSION

The warming on Macquarie Island fits the global temperature trend this century (Folland *et al.* 1984, Jones *et al.* 1986). That carbon-dioxide-induced warming of the lower atmosphere may be involved as a cause is suggested by the observation (Karoly, in press) that significant warming has occurred in the troposphere at 700 mb altitude over Macquarie Island, along with cooling in the lower stratosphere at 50 mb altitude. Karoly found that a number of other Southern Hemisphere meteorological stations show similar patterns. This vertical temperature pattern of warming at lower levels and cooling above is consistent with retention of heat in the troposphere by a carbon dioxide blanket.

Warming has occurred at subantarctic and oceanic islands lying south of the western limb of SO, that is south of the tropical Indian Ocean and of Australia, including Kerguelen Island, Marion Island, New Amsterdam Island (Jacka *et al.* 1984) and Heard Island (Allison & Keage 1986). At these oceanic islands, temperature trends extending over a few decades must reflect similar trends in ocean temperature. On Macquarie Island, Loewe (1957) noted a close connection between simultaneous temperatures of the ocean and the air during 1951–54. He also noted that sea temperatures in 1951–54 were higher than in 1912–14, and that the greatest increase was during summer. The month-by-month increase in sea temperature between the two periods shows the same pattern as that for air temperature from 1949–86 shown in figure 2. There can be little doubt that sea temperatures around Macquarie Island are also warming. Although changes in sea-surface temperature and atmospheric circulation patterns have undoubtedly occurred, their interactions and relative contributions to the warming trend are not known.

Macquarie Island lies at a preferred location for formation of a ridge in the planetary waves of the Southern Hemisphere (van Loon & Jenne 1972, Mo 1986) and near a longitude of frequent blocking and ridge formation (Wright 1974, Ramaswamy & Pareek 1978, Trenberth & Mo 1985), as well as at the junction between western and eastern limbs of SO. This key location in the Southern Hemisphere atmospheric circulation, as well as its isolation in the high latitudes, makes the island an indispensible meteorological station, particularly for upper atmospheric studies.

The temperature rise of 1°C since 1949 is substantial, in view of the mean annual temperature of 4.8°C (1949–86) and the probability that warming was occurring earlier this century. Because the warming is marked in relation to the annual mean, the biological consequences should be addressed. Population size and distribution of plants, seals and sea birds may be affected if the long-term temperature increase continues.

ACKNOWLEDGEMENTS

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REFERENCES

ALLISON, I.F. & KEAGE, P.L., 1986: Recent changes in the glaciers of Heard Island. *Polar Rec.*, 23: 255–271.

ARDENNY, P.E. & KYLE, H.L., 1986: El Nino and outgoing longwave radiation: Observations from Nimbus-7 ERB. *Monthly Weather Rev.*, 14: 415–433.

BERLAGE, H.P., 1957: Fluctuations of the general atmospheric circulation of more than one year, their nature and prognostic value. *Koninklijk Neder. Met. Inst., Mededelingen en Verhandelingen*, 69: 1–152.

BRADLEY, R.S., DIAZ, H.F., KILADIS, G.N. & EISCHEID, J.K., 1987: ENSO signal in continental temperature and precipitation records. *Nature*, 327: 497–501.

CHEN, W.Y., 1982: Fluctuations in Northern Hemisphere 700 mb height field associated with the Southern Oscillation. *Monthly Weather Rev.*, 110: 808–823.

DEACON, G., 1984: *THE ANTARCTIC CIRCUMPOLAR OCEAN*. Cambridge University Press, Cambridge.

FOLLAND, C.K., PARKER, D.E. & KATES, F.E., 1984: Worldwide marine temperature fluctuations 1856–1981. *Nature*, 310: 670–673.

GORDON, N.D., 1986: The Southern Oscillation and New Zealand weather. *Monthly Weather Rev.*, 114: 371–387.

HARNACK, R.P. & HARNACK, J., 1985: Intra and inter-hemispheric teleconnections using seasonal Southern Hemisphere sea level pressure. *J. Clim.*, 5: 283–296.

HENSE, A., 1986: Multivariate statistical investigations of the northern hemisphere circulation during the El Nino event 1982/83. *Tellus*, 38A: 189–204.

JACKA, T.H., 1983: A computer data base for Antarctic sea ice extent. *ANARE Res. Notes*, 13. Antarctic Division, Kingston, Tasmania.

JACKA, T.H., CHRISTOU, L. & COOK, B.J., 1984: A data bank of mean monthly and annual surface temperatures for Antarctica, the Southern Ocean and South Pacific Ocean. *ANARE Res. Notes*, 22. Antarctic Division, Kingston, Tasmania.

JONES, P.D., WIGLEY, T.M.L. & WRIGHT, P.B., 1986: Global temperature variations between 1861 and 1984. *Nature*, 322: 430–434.

KAROLY, D.J., in press: Southern Hemisphere temperature trends: a possible greenhouse gas effect? *Geophys. Res. Lett.*

KELLY, P.M., JONES, P.D., SEAR, C.B., CHERRY, B.S.G. & TAVAKOL, R.K., 1982: Variations in surface air temperatures: Part 2. Arctic regions, 1881–1980. *Monthly Weather Rev.*, 110: 71–83.

KEP, S.L., 1984: A climatology of cyclogenesis, cyclone tracks and cyclolysis in the Southern Hemisphere for the period 1972–1981. *Met. Dep. Univ. Melbourne Publication*, 25. Parkville, Victoria.

LOEWE, F., 1957: A note on sea water temperature at Macquarie Island. *Aust. Met. Mag.*, 19: 60–61.

MO, K.C., 1986: Quasi-stationary states in the Southern Hemisphere. *Monthly Weather Rev.*, 114: 808–823.

PAN, Y.H. & OORT, A.H., 1983: Global climate variations connected with sea surface temperature anomalies in the eastern equatorial Pacific Ocean for the 1958–73 period. *Monthly Weather Rev.*, 111: 1244–1258.

PENG, G. & DOMROS, M., 1987: Connections of the west Pacific subtropical high and some hydroclimatic regimes in China with Antarctic ice–snow indices. *Met. Atmos. Phys.*, 37: 61–71.

PIERREHUMBERT, C., POWELL, F.A. & OLIVER, S., 1984: Continental transport of particulate matter between Australia and Macquarie island. *In* Hartmann, H.F. , O'Heare, J.N., Chiodo, J. & Gillis, R. (Eds): *PROCEEDINGS OF THE EIGHTH INTERNATIONAL CLEAN AIR CONFERENCE*. The Clean Air Society of Australia and New Zealand (2): 741–750.

PITTOCK, A.B., 1971: Rainfall and the general circulation. *PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON WEATHER MODIFICATION*. American Meteorological Society: 330–339.

POLAR REVIEW GROUP, 1980; Polar atmosphere–ice–ocean processes: A review of polar problems in climate research. *Rev. Geophys. & Space Phys.*, 18: 525–543.

RAMAN, C.R.V. & MALIEKAL, J.A., 1985: A "northern oscillation" relating northern hemisphere pressure anomalies and the Indian summer monsoon. *Nature*, 314: 430–432.

RAMASWAMY, C. & PAREEK, R.S., 1978: The southwest monsoon over India and its teleconnections with the middle and upper tropospheric flow patterns over the Southern Hemisphere. *Tellus*, 30: 126–135.

RAPER, S.C.B., WIGLEY, T.M.L., JONES, P.D., KELLY, P.M., MAYES, P.R. & LIMBERT, D.W.S., 1983: Recent temperature changes in the Arctic and Antarctic. *Nature*, 306: 458–459.

RICE, J.E., 1982: The Derivation of a Computer-based Synoptic Climatology of Southern Hemisphere Extra-Tropical Cyclones. Unpublished B.Sc. Honours thesis, University of Melbourne.

SALINGER, M.J. & GUNN, J.M., 1975: Recent climatic warming around New Zealand. *Nature*, 256: 396–398.

TRENBERTH, K.E., 1975: A quasi-biennial standing wave in the Southern Hemisphere and interrelations with sea surface temperature. *Quar. J. R. Met. Soc.*, 101: 55–74.

TRENBERTH, K.E., 1976: Spatial and temporal variations of the Southern Oscillation. *Quar. J. R. Met. Soc.*, 102: 639–653.

TRENBERTH, K.E. & MO, K.C., 1985: Blocking in the Southern Hemisphere. *Monthly Weather Rev.*, 113: 3–21.

VAN LOON, H. & JENNE, R.L., 1972: The zonal harmonic standing waves in the Southern Hemisphere. *J. Geophys. Res.*, 77: 992–1003.

VAN LOON, H. & MADDEN, R.A., 1981: The Southern Oscillation. Part I: Global associations with pressure and temperature in northern winter. *Monthly Weather Rev.*, 109: 1150–1162.

VAN LOON, H. & SHEA, D.J., 1985: The Southern Oscillation. Part IV. The precursors south of 15°S to the extremes of the oscillation. *Monthly Weather Rev.*, 113: 2063–2074.

VAN LOON, H. & SHEA, D.J., 1987: The Southern Oscillation. Part VI: Anomalies of sea level pressure on the Southern Hemisphere and of Pacific sea surface temperature during the development of a warm event. *Monthly Weather Rev.*, 115: 370–379.

WOLTER, K., 1987: The Southern Oscillation and climate over tropical Atlantic, East Pacific and Indian Oceans as captured by cluster analysis. *J. Clim. Appl. Met*, 26: 540–558.

WRIGHT, A.D.F., 1974: Blocking action in the Australian region. *Bur. Met. Aust. Tech. Rep.* 10: 1–29.

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A SOUTHERN VIEW OF THE GLOBAL ATMOSPHERE

by R.J. Francey, G.I. Pearman and D.J. Beardsmore

(with three text figures)

FRANCEY, R.J., PEARMAN, G.I. & BEARDSMORE, D.J., 1988 (viii): A southern view of the global atmosphere. *Pap. Proc. R. Soc. Tasm.*, 122(1): 113–119. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. CSIRO Division of Atmospheric Research, Aspendale, Victoria, Australia 3195.

CSIRO has been monitoring trace gases in the antarctic atmosphere since 1977. An increasing number of trace constituents is being recorded in an effort to better understand human impact on the atmosphere and the consequent climatic and biological effects. This paper focusses on Southern Hemisphere measurements of carbon dioxide, with particular attention to the stable isotope ratios of CO_2.

Secular, interannual, seasonal, and latitudinal variations in concentration, and in the isotope ratios $\delta^{13}C$, $\delta^{18}O$, are examined and their significance to future modelling of the global carbon budget discussed.

The competing requirements for baseline atmospheric monitoring are access to a large, unpolluted, well-mixed air mass and provision of adequate logistical and scientific support. Macquarie Island, remote from continental influences with an established scientific base, combines these requirements to an unusual degree.

Key Words: atmospheric monitoring, carbon cycle, Macquarie Island.

INTRODUCTION

Recognition that the composition of an atmosphere provides a sensitive measure of a planet's life processes came into focus with the NASA quest for life on Mars; an excellent discussion of the compelling atmospheric evidence for life on earth, as reflected in the levels of oxygen, carbon dioxide, methane and many other trace gases was given by Lovelock (1979). More recently, concern about the global impact of industrial and agricultural practices, through changes in atmospheric composition, has gathered momentum. The anticipated changes in the radiative properties of the atmosphere are most publicised in terms of a fear of undesirable climatic change, but other direct and indirect effects on life-forms are also anticipated. A concise overview of these problems has been published by the World Meteorological Organisation (WMO) (1986).

The response to the perception of these changes as a sensitive measure of life processes, of global pollution and of dynamical processes in the atmosphere, has been the establishment of several global atmospheric study programmes. A prime example is the WMO co-ordinated Baseline Air Pollution Monitoring Network, to which the Australian station at Cape Grim (northwestern Tasmania), recently described as "arguably the most comprehensive single surface atmospheric monitoring facility in the world" (Baseline 83–84, 1986), is a major contributor. A second example, on a smaller scale, is a CSIRO programme collecting monthly clean-air samples from Alaska, Hawaii, Samoa, Tasmania, Macquarie Island, Mawson and the South Pole. Preliminary data from both programmes are presented below.

These and similar programmes are the launching pad for major new international initiatives, such as the US Global Tropospheric Chemistry Program and the International Geosphere–Biosphere Program (IGBP), to improve understanding of atmospheric transport, chemical and radiative properties.

THE CSIRO PROGRAMMES

CSIRO commenced monitoring of CO_2 concentration from aircraft over southeastern Australia in 1972 (Pearman *et al.* 1983). Surface observations commenced at Cape Grim (41°S) in 1976, Mawson (68°S) in 1977 and Macquarie Island (54°S) in 1979; these programmes are fully described by Beardsmore & Pearman (1987). *In situ* infrared gas analysers (IRGA) are employed at Cape Grim and Macquarie Island, whereas at Mawson (as well as for the aircraft and at Cape Grim) whole-air samples are collected in 0.5 litre glass flasks for subsequent analysis at CSIRO. Since 1980, the 0.5 litre samples have also been analysed by gas

chromatography for CO_2, CO, CH_4, N_2O, CCl_3F, CCl_2F_2, CH_3CCl_3 and CCl_4 (Fraser *et al.* 1986). (Note that CSIRO measurements of airborne particulate matter over similar periods (Gras & Adriaansen 1985) are not discussed here.)

The monthly collections of clean air from Alaska through to the South Pole (including Macquarie Island and Mawson) commenced in late 1983/early 1984. These involve 5 litre pressurised glass containers which are returned to CSIRO. After gas chromatograph analyses for the range of trace gases listed above, the CO_2 is cryogenically extracted and analysed on a mass spectrometer for $\delta^{13}C$ and $\delta^{18}O$, where, for example,

$$\delta^{13}C = \frac{(^{13}C/^{12}C \text{ sample} - {}^{13}C/^{12}C \text{ reference})}{(^{13}C/^{12}C \text{ reference})}$$

and the δ are normally multiplied by 1000 and expressed in per mil. A full description of this programme is in preparation for publication.

At CSIRO the collection and interpretation of these data involves interaction with modelling studies. The long-term trends and equilibrium distributions of trace gases are modelled with one-dimensional diffusion models (Enting & Pearman 1987), while the modelling of interannual, seasonal and latitudinal variations employs two-dimensional transport and exchange (Pearman & Hyson 1986, Enting & Mansbridge 1987).

The data discussed below are preliminary and recent, and have not been specifically modelled. Emphasis is placed on describing new and unusual aspects of the results, which may involve considerable evolution of the models for a quantitative interpretation.

CO_2 CONCENTRATION RESULTS

The observations of CO_2 concentration in the higher latitudes of the Southern Hemisphere have contributed substantially to our understanding of the global fluxes of that gas across the air–sea interface and in the atmosphere as a whole. While transport of gases in the atmosphere is not always known with great precision, it can be sufficiently constrained to interpret concentration gradients in terms of surface exchanges. For example, the current input of about 5 Gt C yr^{-1} (1 Gt C = 10^{15} g of carbon) as CO_2 from the combustion of fossil fuels, primarily in the Northern Hemisphere, on average maintains about a 3 ppmv concentration gradient between the hemispheres. Similar gradients are established in the Northern Hemisphere, associated with the periodic exchange of carbon with the terrestrial vegetation (Pearman & Hyson 1986).

The increase in atmospheric CO_2 (around 1.5 ppmv yr^{-1}), due to fossil fuel combustion, can be seen in figure 1. The annual mean concentrations at Mawson and Cape Grim (41°S) are very similar, suggesting that, on average, there is little flux of CO_2 between the mid and higher latitudes in the lower atmosphere, and no major surface sink for CO_2 exists at these latitudes. Shipboard observations taken from Australian antarctic supply ships, together with the observations at Cape Grim, Macquarie Island and Mawson (Beardsmore & Pearman 1987) do show, however, that there may be a small regional maximum of concentration around 56°S, at least in the summer months. The maximum concentration is about 1 ppmv higher than at Cape Grim. Komhyr *et al.* (1985) have also suggested that a regional source of CO_2 may exist. It is possible that this source is related to the Antarctic Convergence zone. Perhaps carbon-rich intermediate water comes to the surface in this zone, giving an ocean surface layer with CO_2 partial pressure (pCO_2) substantially highly than that in the atmosphere. Only ocean pCO_2 measurements will confirm this.

Both Macquarie Island and Mawson exhibit somewhat larger seasonal variations in concentration than occurs at Cape Grim. Early summer concentrations are similar at both southern stations but, during the following months, Mawson appears to show a more definite decrease.

This larger seasonal amplitude at Mawson has become particularly obvious in our 1985 and 1986 data. The reason for this effect is not known. It is possible that it is a relatively local event, involving the disappearance of the sea ice and the summer melting of ice in the coastal region (Budd 1980). The annual supply of very cold fresh water, low in carbon content but with high solubility for CO_2, may provide the suggested sink for atmospheric CO_2. If it is a coastal effect, for example extending over 10° of latitude and through a depth of atmosphere of 1 km, then it can be calculated that this decrease represents a surface sink of order 10^{-2} Gt C. Given that the major fluxes in the carbon cycle are of order 1 Gt C, this annual feature, or the variations in its magnitude from year to year, are unlikely to be of great importance in the global perspective, though there may be appreciable influences on the local marine biosphere.

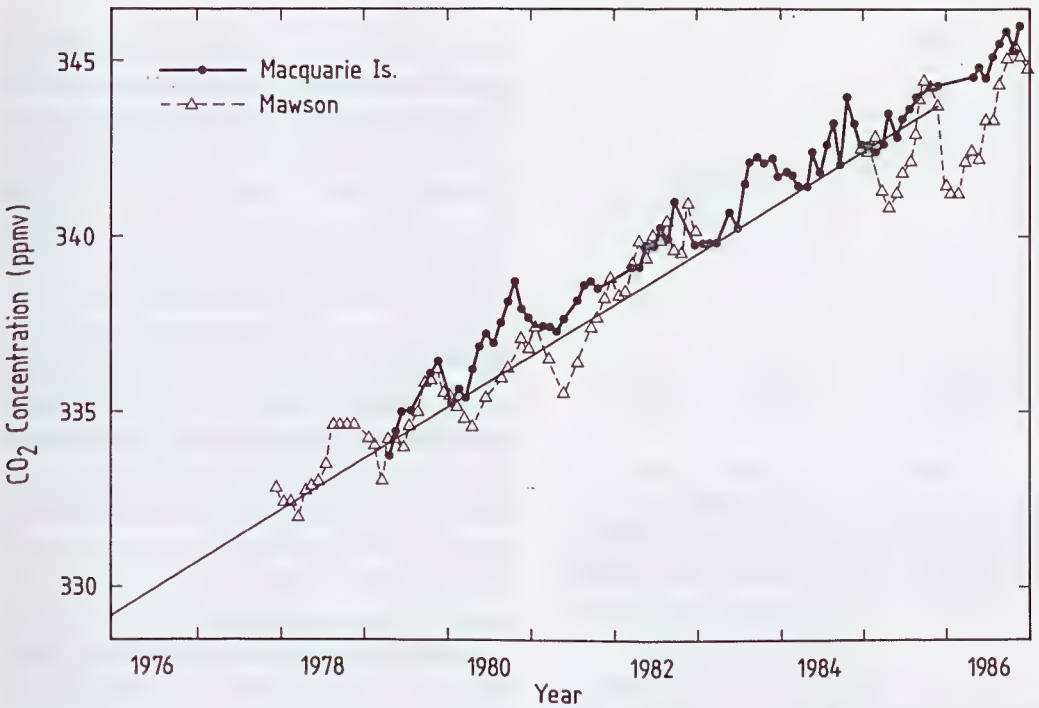

FIG. 1 — Mean monthly carbon dioxide concentrations at Macquarie Island and Mawson. The straight line is a linear regression to the data from the Australian Baseline Air Pollution Station at Cape Grim, Tasmania.

CARBON ISOTOPE RESULTS

An important generalisation for a qualitative interpretation of the stable carbon isotope ($^{13}C/^{12}C$) data is that atmospheric values are mainly determined by CO_2 exchange involving terrestrial biological material. The dominating mechanism is a discrimination against the heavier isotope, ^{13}C, or a preference for ^{12}C, shown by plants during photosynthesis (Farquhar *et al.* 1982, Francey & Farquhar 1982). Thus, a net uptake of CO_2 by plants results in an increase in atmospheric $\delta^{13}C$, whereas respiratory CO_2 or CO_2 from the combustion of terrestrial biological material (including fossil fuel) decreases $\delta^{13}C$.

In equilibrium exchange of CO_2 with surface water, in particular the oceans, the fractionation that occurs on entry is practically balanced by a reverse fractionation on exit, with no net result (for example, Siegenthaler & Munnich 1981). Note that plants growing in the ocean mixed layer also fractionate carbon; however, since the biological carbon is largely extracted from, and returned to the ocean, and since dissolved CO_2 is a tiny fraction of the total available carbon, the influence of marine life on atmospheric isotope ratios is generally negligible.

The time constant for CO_2 equilibration with the ocean surface water is about ten times longer than most gases (for example O_2), and is around one year; the time constant for carbon isotope equilibrium is even longer, by a factor equal to the ratio of total inorganic carbon/dissolved CO_2; this ratio ranges from about 180 in warm water to about 150 in cold water (Broecker & Peng 1982). A factor to be kept in mind here is that for a given perturbation of CO_2 concentration and isotope ratio, the percentage change in $\delta^{13}C$ might considerably exceed the percentage change in CO_2, even though the equilibration of CO_2 is much more rapid. This merely reflects the fact that $\delta^{13}C$ is essentially a high precision measurement of a difference from a reference value which happens to be close to the equilibrium value.

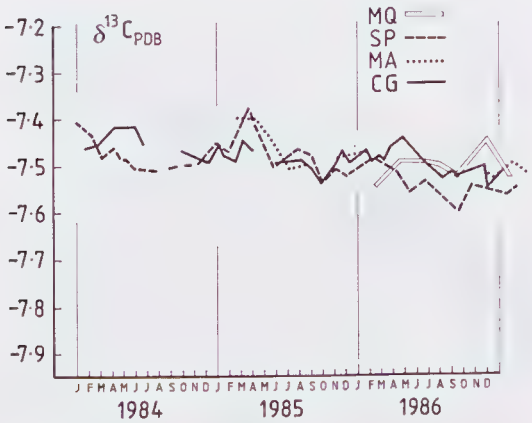

FIG. 2 — Preliminary (smoothed) stable carbon isotope ratios, $\delta^{13}C$, in CO_2 extracted from 5 litre flasks of air collected at Cape Grim, Macquarie Island, Mawson and South Pole. Values are in per mil, expressed in the CSIRO (1980) PDB reference scale. (Note: corrections have been applied for a N_2O contribution to mass 44.)

In the present context, that is, in examining data south of Cape Grim, the absence of appreciable industrial and terrestrial biospheric activity implies an absence of sources of isotopic variation south of Cape Grim. This is significant, given that we have already described sources of CO_2 concentration variation south of Cape Grim.

In figure 2 the preliminary stable carbon isotope values are presented for years 1984–86, for Cape Grim, Macquarie Island, Mawson and South Pole.

The most obvious feature is the steady trend of decreasing $\delta^{13}C$ evident at all stations with sufficiently long record. The change is about 0.03 per mil yr^{-1} which, for a concentration change of 1.45 ppmv yr^{-1}, implies a coefficient of around 0.02 per mil $ppmv^{-1}$ (Francey 1985). These numbers are now relatively well established and understood in terms of the known input of ^{13}C-depleted CO_2 from fossil fuel combustion, mainly in the Northern Hemisphere, coupled with ocean uptake (Pearman & Hyson 1986). As discussed by these authors, and others, there is some controversy over the fact that the total release of carbon from forest clearing and agriculture is constrained by these measurements to values small compared to fossil fuel release. This is contrary to estimates from some ecological studies.

An important objective in setting up the study was to define more accurately the latitudinal gradient in $\delta^{13}C$ resulting from the Northern Hemisphere fossil fuel release (present estimates give a north-south high-latitude difference of around minus 0.2 per mil), which permits important refinements of the parameterisations of atmospheric transport and surface exchange. A close study of the data of figure 2 does, in fact, suggest systematic differences between Southern Hemisphere stations. For example, in 1984 and 1986, values of $\delta^{13}C$ at South Pole are distinctly lower than at Cape Grim (and Macquarie Island), while Mawson appears closer to South Pole, at least in 1985. Model studies (Heimann *et al.* 1985, Pearman & Hyson 1986) predict a lower value at high latitudes as a result of the high altitude at South Pole (2800 m), coupled with a predicted decrease in $\delta^{13}C$ with altitude, apparently reflecting southwards transport of ^{13}C-depleted Northern Hemisphere air in the upper arm of the Hadley cell. Figure 2 suggests inter-annual variations (with the gradient effectively absent in 1985), possibly related to variations in this transport.

Seasonality is evident in the Cape Grim data, with a $\delta^{13}C$ maximum in early March, practically coincident with a concentration minimum. This is characteristic of exchange with terrestrial biosphere, and the coefficient of 0.05 per mil $ppmv^{-1}$ is consistent with this (Francey 1985). The 2D transport and exchange models predict a decoupling of concentration and isotopic seasonal variations going south from Cape Grim, mainly due to an increasing oceanic contribution to the concentration changes. There is some evidence for this decoupling in figure 2; however, several more years data are required for a quantitative description of this effect. For example, there is a suggestion of enhanced $\delta^{13}C$ at Mawson and South Pole in the late summer of 1985, coincident with the concentration dip observed at Mawson — if real, we have no simple explanation for such an isotope variation, and there is no evidence for similar variations in the other years.

The only other known programme (with comparable precision to the CSIRO programme) producing clean-air $\delta^{13}C$ from a global network is described by Mook *et al.* (1983). Their recent data exhibit a large interannual variation occurring around the globe throughout 1983–84 (Heimann *et al.* 1986). The variation is characterised in their South Pole record by a decline in early 1983 $\delta^{13}C$ to a value at least 0.1 per mil below the long-term linear trend (established between 1977 and 1982), followed by a recovery to the long-term trend line by the end of 1984. Such a variation implies appreciable net fluxes of biospheric CO_2 which, with current models of carbon transport and

exchange, should be accompanied by a concentration perturbation of some 2 ppmv; no such CO_2 concentration perturbation is observed. An isotope variation of 0.1 per mil throughout 1983–84 is definitely excluded by the data of figure 2, suggesting a systematic error in the Heimann *et al.* data.

OXYGEN ISOTOPE RESULTS

Data on the oxygen isotope ratio ($^{18}O/^{16}O$) in atmospheric CO_2 were originally collected solely for the purpose of correcting the carbon isotope data, to distinguish $^{13}C^{16}O^{16}O$ from $^{12}C^{16}O^{17}O$ at mass 45 (Craig 1953). Inspection of several years of Cape Grim data revealed marked systematic behaviour, and led to a biogeophysical hypothesis to explain the observed variations (Tans *et al.* 1986).

A distinguishing feature of the Cape Grim *in situ* isotope programme is the pre-drying of air prior to CO_2 extraction and analysis (Francey & Goodman 1986). This feature is also employed in the 5 litre flask sampling. It is now apparent that the drying prevents CO_2 hydration followed by equilibration of oxygen isotopes (particularly during extended sample storage), and thus information on the original CO_2 oxygen isotope is maintained. The latitudinal gradients emerging from the global 5 litre flask programme strongly support the original hypothesis (Francey & Tans 1987).

Basically, the dissolution of CO_2 in water, and its subsequent hydration, are considered necessary for the modification of atmospheric CO_2 $\delta^{18}O$; direct exchange with other sources of atmospheric oxygen (for example O_2, water vapour) appears to be negligible. Similarly, the injection of fossil fuel CO_2 has little effect on the $\delta^{18}O$ of atmospheric CO_2 (resulting in a latitudinal difference of only around 0.2 per mil). Hydration in the more obvious sources of water, for example, the oceans or cloud water, is governed by the CO_2 hydration rate; this turns out to be far too slow to explain the observed seasonal and interannual variations. Leaf water provides an answer because of the presence of the enzyme carbonic anhydrase. This enzyme is ubiquitous in plants, and the catalysis of CO_2 hydration by carbonic anhydrase is one of the fastest known enzymatic reactions — at room temperature the hydration process is speeded around a million times. Thus we have an appreciable source of water in which there is rapid and complete equilibration of CO_2 and its oxygen isotopes.

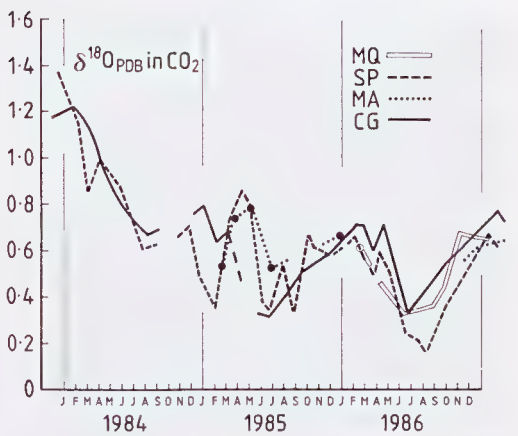

FIG. 3 — Preliminary (smoothed) oxygen isotope ratios, $\delta^{18}O$, in CO_2 extracted from 5 litre flasks of air collected at Cape Grim, Macquarie Island, Mawson and South Pole. Values are in per mil, expressed in the CSIRO (1980) PDB reference scale. (Note: corrections have been applied for a N_2O contribution to mass 44.)

With this model, factors which influence $\delta^{18}O$ in atmospheric CO_2 are then

(1) the ground water $\delta^{18}O$ — to a first approximation this is determined by the temperature of cloud condensation, with lower $\delta^{18}O$ at lower temperatures; the dominant feature is a latitudinal gradient from equator to pole, with lower $\delta^{18}O$ at the poles; a secondary effect is related to preferential precipitation of the heavier isotope during rain — thus $\delta^{18}O$ decrease going from the coast towards the interior of continents;

(2) the fractionation which occurs due to evaporation from leaves, resulting in leaf water appreciably heavier (with higher $\delta^{18}O$) than ground water; the amount of fractionation of leaf water compared to ground water depends inversely on the humidity;

(3) the total amount of CO_2 cycled through leaf water — to a first approximation this depends on the distribution of trees; second-order effects may relate to large-scale changes in gross biospheric turnover.

An important perspective on this process is the huge amounts of CO_2 exchange required to maintain the observed gradients against rapid atmospheric mixing. Francey & Tans (1987) estimate that exchange of some 200 Gt C yr^{-1} is required to explain the observed Northern Hemisphere gradient, compared to a total net

primary production of all plants on earth of 40–70 Gt C yr^{-1}, or a global CO_2 exchange across the air-sea interface of around 90 Gt C yr^{-1}.

With this background, we can examine the first detailed data on $\delta^{18}O$ in CO_2 values for the Southern Hemisphere in figure 3. There is quite good agreement in mean level between all four stations, as might be expected if the major source of the variations is associated with terrestrial biosphere, most of which is well to the north of Cape Grim. The strong coherent seasonality is also evidence that no major sources or sinks for $\delta^{18}O$ variations occur in the southern region. No explanation so far exists for the strong interannual variability, particularly evident in 1984, though with the dependence on rain distribution, humidity and biological activity, we can speculate that the climatic perturbations associated with the unusually severe El Nino event of 1982–83 may be a factor.

Perhaps the most interesting suggestion from the preliminary data is that, as with $\delta^{13}C$, Mawson is more closely associated with South Pole and Cape Grim with Macquarie Island. Since both species are linked to sources mainly north of Cape Grim, but involving somewhat different source mechanisms, this is reinforcement of the suggestion that transport in the upper levels of the atmosphere is a factor.

CONCLUSIONS

In summary, the CO_2 concentration and carbon isotope measurements, coupled with modelling studies, have yielded the following tentative description of the carbon cycle over the Southern Ocean. On the northern limits of the Southern Ocean (around 35°S) there is significant oceanic uptake, with a small seasonal exchange driven primarily by the effects of temperature on pCO_2; the carbon isotope data indicate that, at Cape Grim, the main seasonality in concentration is derived from exchange with terrestrial biosphere. Going south to the Antarctic Convergence, some uptake of CO_2 at the surface still occurs, although the seasonality now appears to be controlled by the activity of the marine biosphere. At the Convergence, there appears to be a release of CO_2 to the atmosphere. At higher latitudes and on the coast of Antarctica, there is no evidence of oceanic uptake or marine biological effects, with the exception of a regional (unmodelled) scale late summer uptake on the coast. In terms of the global budget in this region, the pCO_2 of surface water is probably maintained close to atmospheric levels by deep vertical mixing.

In addition, the carbon isotope results suggest refinements to the parameterisation of Southern Hemisphere transport at upper levels of the atmosphere. This is supported by the oxygen isotope data. Given apparent difficulties with past methods, the isotope data presented here give a first detailed picture of the variations in these species in the Southern Hemisphere.

The challenge of the current measurement programmes is to provide conclusive evidence for the existence, or otherwise, of these features of the carbon cycle, and in particular to understand more about the relative roles of surface exchanges and interannual atmospheric transport changes. A sound understanding of the carbon cycle in this region is important if accurate predictions of future levels of CO_2 are to be made, especially if the dynamics of the ocean are to evolve with the changing global climate.

It is against this background that the importance of Macquarie Island as an atmospheric monitoring site becomes apparent. Few other latitude bands in the world are so poorly represented in terms of human activities, biologically active land surfaces and continental shelfs, and orographic disturbance to wind fields. This remoteness is one essential ingredient for global monitoring, the other is a substantial level of logistical and scientific support. With the excellent support and improving facilities provided by the Antarctic Division, Macquarie Island has the potential for playing a major role in future global atmospheric research.

ACKNOWLEDGEMENTS

Geoff Richards and Helen Goodman played major roles in sample collection and isotopic analyses respectively. The project receives support from a Department of Resources and Energy NERDDC grant. The head office staff of the Australian Antarctic Division and expeditioners at Macquarie Island and Mawson have exhibited a cheerful and unfailing co-operation over the years, for which we are most grateful.

REFERENCES

BASELINE 83–84, 1986 (Francey, R.J. & Forgan, B.W., Eds). Department of Science, Bureau of Meteorology, and CSIRO, Division of Atmospheric Research, Melbourne, Australia.

BEARDSMORE, D.J. & PEARMAN, G.I., 1987: Atmospheric carbon dioxide measurements in the Australian region: Data from surface observatories. *Tellus*, 39B: 42–66.

BROECKER, W.S. & PENG, T-H., 1982: *TRACERS IN THE SEA*. Lamont-Doherty Geological Observatory, Columbia University, Pallisades, N.Y.

BUDD, W.F., 1980: The importance of the Antarctic region for studies of the atmospheric carbon dioxide concentrations. *In* Pearman, G.I. (Ed.): *CARBON DIOXIDE AND CLIMATE: AUSTRALIAN RESEARCH*. Australian Academy of Science, Canberra.

CRAIG, H., 1953: The geochemistry of the stable carbon isotopes. *Geochim. Cosmochim. Acta*, 3: 53–92.

ENTING, I.G. & MANSBRIDGE, J.V., 1987: Preliminary studies with a two-dimensional atmospheric transport model using transport fields derived from a GCM. *CSIRO Div. Atmos. Res. Tech. Pap.* No.14.

ENTING, I.G. & PEARMAN, G.I., 1987: Description of a one-dimensional carbon cycle model calibrated using techniques of constrained inversion. *Tellus*, 39B: 459–476.

FARQUHAR, G.D., O'LEARY, M.H. & BERRY, J.A., 1982: On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Aust. J. Plant Physiol.*, 9: 121–137.

FRANCEY, R.J., 1985: Cape Grim isotope measurements — a preliminary assessment. *J. Atmos. Chem.*, 3: 247–260.

FRANCEY, R.J. & FARQUHAR, G.D., 1982: An explanation of $^{13}C/^{12}C$ variations in tree rings. *Nature*, 297: 28–31.

FRANCEY, R.J. & GOODMAN, H.S., 1986: Systematic error in, and selection of, insitu $\delta^{13}C$. *In* Francey, R.J. & Forgan, B.W. (Eds): *BASELINE 83–84*. Department of Science, Bureau of Meteorology, and CSIRO, Division of Atmospheric Research, Australia: 27–36.

FRANCEY, R.J. & TANS, P.P., 1987: The latitudinal variation in oxygen-18 of atmospheric CO_2. *Nature*, 327: 495–497.

FRASER, P.J., HYSON, P., RASMUSSEN, R.A. CRAWFORD, A.J. & KHALIL, M.A.K., 1986: Methane, carbon dioxide and methylchloroform in the Southern Hemisphere. *J. Atmos. Chem.*, 4: 3–42.

GRAS, J.L. & ADRIAANSEN, A., 1985: Concentration and size variation of condensation nuclei at Mawson, Antarctica. *J. Atmos. Chem.*, 3: 93–106.

HEIMANN, M., KEELING, C.D. & MOOK, W.G., 1985: A three dimensional model of Atmospheric CO_2 transport based on observed winds I. Observational data and model. Presented at the conference "Atmospheric carbon dioxide, its sources, sinks and global transport", Commission on Atmospheric Chemistry and Global Pollution of IAMAP, Kandersteg, September 1985.

KOMHYR, W.D., GAMMON, R.H., HARRIS, T.B., WATERMAN, L.W., CONWAY, T.J., TAYLOR, W.R. & THONING, K.W., 1985: Global atmospheric CO_2 distribution and variations from 1968–1982; NOAA/GMCC flask sampling data. *J. Geophys. Res.*, 90: 5567–5596.

LOVELOCK, J.E., 1979: GAIA: *A NEW LOOK AT LIFE ON EARTH*. Oxford University Press, Oxford.

MOOK, W.G., KOOPMANS, M., CARTER, A.F. & KEELING, C.D., 1983: Seasonal, latitudinal and secular variations in the abundance and isotopic ratios of atmospheric carbon dioxide I. Results from land stations. *J. Geophys. Res.*, 88: 915–933.

PEARMAN, G.I., BEARDSMORE, D.J. & O'BRIEN, R.C., 1983: The CSIRO (Australia) atmospheric carbon dioxide monitoring program: Ten years of aircraft data. *CSIRO Div. Atmos. Phys. Tech. Pap.* No.45.

PEARMAN, G.I. & HYSON, P., 1986: Global transport and inter-reservoir exchange of carbon dioxide with particular reference to stable carbon isotopic distributions. *J. Atmos. Chem.*, 4: 81–124.

SEIGENTHALER, U. & MUNNICH, K.O., 1981: $^{13}C/^{12}C$ fractionation during CO_2 transfer from air to sea. *In* Bolin, B. (Ed.): *SCOPE 16. Carbon cycle modelling*. John Wiley and Son, Chichester: 249–257.

TANS, P.P., FRANCEY, R.J. & PEARMAN, G.I., 1986: Large scale variations in $\delta^{18}O$ of atmospheric CO_2. *In* Francey, R.J. & Forgan, B.W. (Eds): *BASELINE 83–84*. Department of Science, Bureau of Meteorology, and CSIRO, Division of Atmospheric Research, Australia: 10–14.

WORLD METEOROLOGICAL ORGANISATION GLOBAL OZONE RESEARCH AND MONITORING PROJECT, Report No.16, 1986: Atmospheric Ozone 1985 (NASA, FAA, NOAA, UNEP, WMO, CEC, BFT).

(accepted 16 November 1987)

A QUANTITATIVE INVESTIGATION INTO SCAVENGING OF AIRBORNE SEA SALT OVER MACQUARIE ISLAND

by Michael Mallis

(with ten tables and two text-figures)

MALLIS, M., 1988 (viii): A quantitative investigation into scavenging of airborne sea salt over Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 121–128. Paper presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Physics Department, La Trobe University, Bundoora, Victoria, Australia 3083.

Through study of rainwater collections made at Macquarie Island, during the 1985–86 austral summer, it was possible to compare previous theoretical predictions of sea-salt scavenging in precipitation with actual observations. Some earlier rainwater collections are found to have grossly overestimated the initial salt budget. It is shown that the earlier theoretical investigation adequately accounts for the salt budget and that sea-spray droplets play little part in salt scavenging by precipitation over most parts of the island.
Key Words: sea salt, salt scavenging, Macquarie Island.

INTRODUCTION

Calculations, based on actual rainwater measurements obtained from Evans (1970) and Jenkin (1972), led to the conclusion that in- and below-cloud scavenging processes, due to solid sea-salt particles, could only account for part of the observed total salt (NaCl) budget over Macquarie Island, the balance being due to sea-spray droplets (Mallis 1985). Subsequently, rainwater collections were performed, from December 1985 to April 1986 inclusive, for various sites over the island. Chemical analysis of chlorides and sulphates tends to support previous theoretical predictions (Mallis 1985) and reject Evans' data; Jenkin's data are also found to be suspect, though to a lesser degree. It can be demonstrated that it is possible to account for the expected salt budget without having to make up the difference by resorting to sea spray.

Even though drastic simplifications and parameterisations have been made in order to simplify the theory, they do make problems more tractable. This report follows up earlier work in this field and provides quantitative data to support previous theoretical predictions.

PROCEDURE

The experimental procedure for collecting water samples is described below. In all, four sites were chosen as representative of anticipated different conditions to be encountered over the island and within easy access of the Australian National Antarctic Research Expedition (ANARE) station. Table 1 lists these sites, together with their approximate altitudes and commissioning dates. Site 1 was located in the Bureau of Meteorology

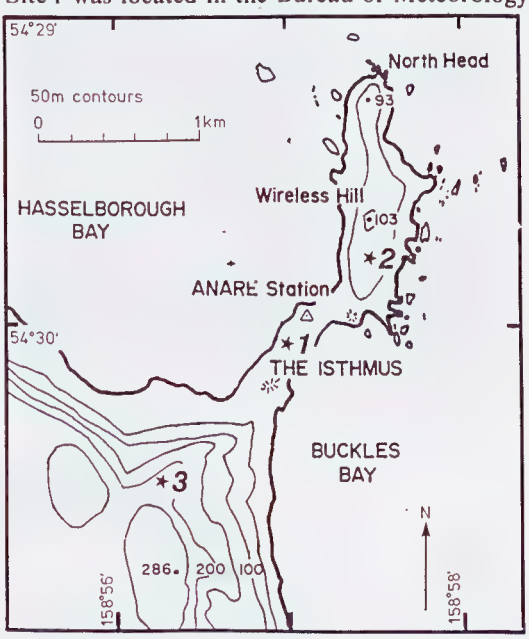

FIG. 1 — Map of the isthmus and its immediate environ, with approximate positions of rainwater collection sites 1, 2 and 3. Site 4 is located about 3 km south of site 3.

TABLE 1

Water collection site details

Site name	Site number	Commissioning date	Altitude (m)
Isthmus	1	13 Dec 1985	4
Wireless Hill	2	18 Dec 1985	~100
Ski Hut	3	29 Dec 1985	~220
Mt Elder	4	23 Feb 1986	~300

Instrument Enclosure on the isthmus; site 2 was atop Wireless Hill, located near Lambing Gully, which also afforded some protection from direct wind gusts; site 3 was situated near North Mountain and close to the ski hut (see fig. 1). Site 4 was located on the plateau proper, at the base of Mt Elder on the western side. As only three collection containers were in use, sites 3 and 4 were alternated. Sites 2 and 3 approximate very closely to those originally chosen by Jenkin (1972); site 1 is, of course, identical. However, the sampling procedure adopted for this study differs from that used by Evans (1970) and Jenkin (1972) to the point where it is concluded that spurious results were originally obtained. This discrepancy is discussed further later.

Before each collection container (a plastic bucket with a lip diameter of 255 mm) was deployed in the field it received a thorough wash, first with tap and then with de-ionised water. In the field, each bucket was set into a solid styrene foam block which was firmly anchored to the soft soil. Rainwater was removed from these buckets only during times of no precipitation. All three would be attended to within one hour or, in the case of site 4, within two hours. Rainwater was decanted on-site into sterile 250 ml plastic bottles. About 50-100 ml of de-ionised water was used to wash the bucket and also decanted, to help assure the integrity of the next water sample and keep a running check in the event of possible contamination arising through the water collection procedure. In order to arrest biological degradation which might otherwise alter the chemical composition, enough chloroform was added, in the laboratory, to each decanted water bottle, including wash water, to make up about a 10% solution.

Complete meteorological records were kept for the period of this study to help later correlation of rainfall events with subsequent salt concentrations for each site. These meteorological records are, strictly speaking, accurate only for site 1 but can be extrapolated to other sites with caution. Subsequent chemical analysis was performed by the CSIRO Division of Atmospheric Research in Melbourne.

In all, 263 250-ml sample bottles were collected, representing about 43 litres of rainwater over a four-month period. The success of this project depended upon obtaining enough water samples, covering as many individual precipitation events as possible, to perform subsequently a statistically relevant and meaningful analysis of the data. (Note that the chemical analysis accuracy is given as ±3.5% whilst rainwater volumes are accurate to ±0.1 ml.)

TABLE 2

Monthly mean rainfall data for site 1

Month	Total rainfall	No. days rainfall	Approx. hrs rainfall	Average rainfall rate ($mmhr^{-1}$)
Dec 1985	23.8	9	54	0.441
Jan 1986	73.0	25	210	0.348
Feb 1986	84.8	18	174	0.487
Mar 1986	136.2	28	357	0.382
Apr 1986	41.4	9	117	0.354

ANALYSIS

A full theoretical description of scavenging by convective diffusion of aerosol particles by cloud droplets is given in Mallis (1985) and will not be repeated here. However, the same mathematical symbols and definitions are retained.

A reasonable estimate of the scavenging coefficient, Λ, has been given by Pruppacher & Klett (1980), taking into account both in- and below-cloud scavenging. Λ is given by

$$\Lambda \approx 4.2 \times 10^{-4} \bar{E} R^{0.79} \text{ sec}^{-1}$$

where $\bar{E}$ is the characteristic collision frequency for drop-droplet interactions and R is the rain rate in mmhr^{-1}. $\bar{E}$ is taken to equal 0.83, from Crandall *et al.* (1973). An estimate of R for site 1 is found from table 2, where the total rainfall rate is calculated as a monthly mean. The total mean rainfall rate over the five months was found to be $\bar{R} = 0.402$ mmhr^{-1}, with a standard deviation of 0.060 mmhr^{-1}.

An estimate of the scavenged deposition rate, Q, of NaCl in kg/ha/yr is given by

$$Q = \Lambda\, n_x t_{1/2}\, W_L^{-1} A \qquad (1)$$

where A is a conversion factor ($\text{kgcm}^3/\text{ha/yr}$), n_x is a mean NaCl particle concentration (cm^{-3}), $t_{1/2}$ is the half-life of NaCl particles and W_L is the liquid water content of cloud (gcm^{-3}). Best estimates of $t_{1/2}$, n_x and W_L for average conditions are 8.56×10^5 sec, 167 cm^{-3} and 0.6×10^{-6} gcm respectively. Only n_x is considered to vary significantly over the three collection sites, and so Λ, $t_{1/2}$ and W_L are considered constant in the ensuring analysis.

As determined earlier (Mallis 1985), it is possible to estimate the amount of in-cloud scavenging qualitatively, using equation (1). This was found to be about ($D^1 \doteq$) 58 kg/ha/yr of NaCl deposited in precipitation. This value was estimated, using the above variable values of n_x, $t_{1/2}$ and W_L, and taking $R = R_X = 0.401$ mmhr_{-1}. Note that R_X and $\bar{R}$ compare extremely favourably. Also calculated was the total expected amount of NaCl deposited due to in- and below-cloud scavenging. This was found to be about ($Q_m \doteq$) 411 kg/ha/yr for site 1. Having access to quantitative data, it is now possible to improve the original scavenging model and compare with actual observations as a test of its accuracy.

A new estimate of the actual in-cloud scavenging rate, D, can be given by

$$D = D'(\bar{n}_A)/(\bar{n}_x) \qquad (2)$$

where $\bar{n}_A$ is an estimate of the average NaCl particle concentration at cloud altitudes and in region A;

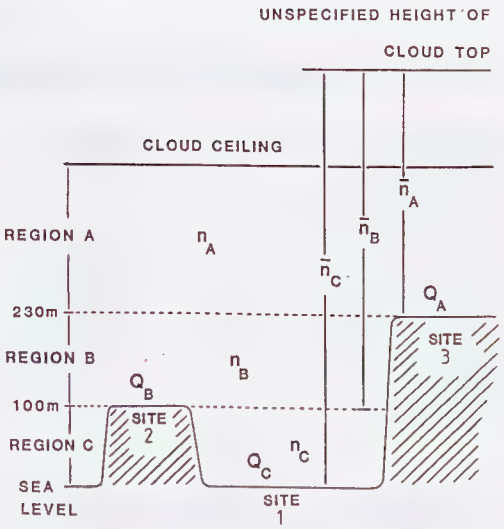

FIG. 2 — Schematic diagram of isthmus as viewed from west looking east, with regions A, B and C defined, along with relevant parameters.

similarly $\bar{n}_B$ and $\bar{n}_C$ are the averaged particle concentration values calculated within regions B and C, and regions A, B and C respectively (fig. 2 indicates these regions). These averaged particle concentrations are given by

$$\bar{n}_A = \bar{n}_x(P_A/Q_A) \qquad (3)$$

$$\bar{n}_B = n_x[(P_B - D)/Q_B] \qquad (4)$$

$$\bar{n}_C = n_x[(P_C - D)/Q_C] \qquad (5)$$

where Q_A, Q_B and Q_C are the estimated total deposition rates due to scavenging of NaCl in precipitation within regions A, B and C respectively; also P_A, P_B and P_C are the actual deposition rates, as measured at the bottom of regions A, B and C respectively. P_A, P_B and P_C values are determined in the next section.

After making due allowance for differing rainfall rates within each region, Q_A, Q_B and Q_C can be estimated from

$$Q_A = Q_M(R_x/R_A)^{0.79} \qquad (6)$$

$$Q_B = Q_M(R_x/R_B)^{0.79} \qquad (7)$$

$$Q_C = Q_M(R_x/R_C)^{0.79} \qquad (8)$$

where R_A, R_B and R_C are the estimated rainfall rates for regions A, B and C respectively. Table 3 lists five separate collections made at all sites. Total volume of rainwater plus the percentage difference between sites 2 and 3 with respect to site 1 is given.

TABLE 3

Volume of rainwater collected from all available sites at approximately the same time

Collection date/period*	Collection site	Volume rainwater collected (ml)	Percentage difference WRT site 1
29 Dec 1985	1	284.6	–
(2)	2	369.3	29.8
2 Jan 1986	1	381.6	–
(3)	2	476.0	24.7
	3	548.0	43.6
9 Jan 1986	1	167.2	–
(6)	2	233.4	39.6
	3	252.9	51.3
13 Jan 1986	1	159.1	–
(4)	2	170.9	7.4
	3	208.5	31.0
23 Feb 1986	1	3344.6	–
(12)	2	3728.9	11.5
	4	4305.6	17.2

* Numbers in parentheses indicate sample period, in days, over which collections were made.

These mean percentage differences of sites 2 and 3 are listed in table 4, along with their estimated mean rainfall rate. It is readily observed that $R_A > R_B > R_C$ on average.

Using the following equations, estimates of particle concentrations within regions A, B and C respectively are

$$\bar{n}_A = n_A \quad (9)$$

$$\bar{n}_B = [n_A(P_A-D)+n_B(P_B-P_A)]/P_B-D \quad (10)$$

$$\bar{n}_C = [n_A(P_A-D)+n_B(P_B-P_A)+n_C(P_C-P_B)]/P_C-D \quad (11)$$

Note that the RHS of equations (10) and (11) are, in fact, weighted means used in determining $\bar{n}_B$ and $\bar{n}_C$. Equating equations (3), (4) and (5) with (9), (10) and (11) respectively, and substituting for Q_A, Q_B and Q_C from equations (6), (7) and (8) respectively, solutions for n_A, n_B and n_C can be found. Table 5 summarises these findings. Note that, although $n_C/n_A = 1/5.9$ and $n_B/n_A = 1/3.2$, coincidentally $P_A/P_C = 1/6.5$ and $P_A/P_B = 1/3.7$. The estimated in-cloud NaCl deposition rate, D, is calculated from equation (1) and is found to be 69.3 kg/ha/yr.

Table 6 lists the volume of rainwater collected at site 1 and the rainfall amount as recorded by the Bureau of Meteorology rain gauge for the same time interval. Also listed is the calibration ratio, r, of rainwater collected to rainfall measured. The relative constancy of this ratio over the 23 collections is reasonably good, considering that Macquarie Island experiences much wind, making precipitation collections difficult even at the best of times. Although only site 1 had a rain gauge, the calibration ratio is taken to be valid for all collection sites. The mean value of r was found to be 45.9 ml/mm, with a standard deviation of 7.8 ml/mm.

TABLE 4

Estimated mean rainfall rates for sites 1, 2 and 3

Site	Rainfall rate*	
	Mean percentage difference WRT site	Estimated mean R ($mmhr^{-1}$)
1	–	0.402 (0.060)
2	25.4 (13.5)	0.504 (0.456)
3	42.0 (10.2)	0.571 (0.443)

* Numbers in parentheses give one standard deviation about the mean.

TABLE 5

Summary of deposition and rainfall rate, and mean particle concentration for various altitudes over Macquarie Island

Region	Total NaCl deposited at base of region P (kg/ha/yr)	Estimated rainfall rate within region R ($mmhr^{-1}$)	Estimated particle concentration within region n (cm^{-3})
A	370 (205)	0.571 (0.443)	200 (121)
B	655 (798)	0.504 (0.456)	376 (400)
C	2423 (2539)	0.402 (0.060)	1182 (1198)

* Numbers in parentheses indicate standard deviation of variable.

TABLE 6

Summary of rainwater and rainfall data for site 1

Date	Rainwater collected (m)	Rainfall recorded (mm)	Calibration ratio, r (ml/mm)
18 Dec 1985	683.5	15.2	45.0
18 Dec 1985	163.1	3.3	49.4
27 Dec 1985	92.6	2.1	44.1
29 Dec 1985	302.6	6.8	44.5
30 Dec 1985	300.2	6.2	48.4
31 Dec 1985	53.2	1.4	38.1
2 Jan 1986	326.3	6.0	51.0
3 Jan 1986	434.0	9.8	44.3
9 Jan 1986	167.2	6.2	27.0
13 Jan 1986	159.1	3.6	44.2
17 Jan 1986	898.0	15.6	57.6
1 Feb 1986	760.8	29.0	26.2
6 Feb 1986	409.6	8.6	47.6
11 Feb 1986	226.1	6.0	37.7
23 Feb 1986	3728.9	67.6	55.2
3 Mar 1986	2130.9	50.0	42.6
7 Mar 1986	846.1	16.6	51.0
9 Mar 1986	133.4	2.6	51.3
10 Mar 1986	255.5	5.0	51.1
25 Mar 1986	2359.4	51.0	46.3
29 Mar 1986	752.9	13.8	54.6
8 Apr 1986	1879.7	39.9	47.1
9 Apr 1986	220.0	4.3	51.2
Mean			45.9
Standard deviation			7.8

TABLE 7

NaCl concentrations collected from all available sites at approximately the same time

Collection date/period*	Collection site	[NaCl] (mm)	Percentage difference WRT site 1
29 Dec 1985	1	1520	–
(2)	2	853	-43.9
2 Jan 1986	1	5819	–
(3)	2	1279	-78.0
	3	1393	-76.1
9 Jan 1986	1	2964	–
(6)	2	588	-80.2
	3	696	-76.5
13 Jan 1986	1	1166	–
(4)	2	553	-52.6
	3	540	-53.7
23 Feb 1986	1	1606	–
(12)	2	743	-53.7
	4	319	-80.1

* Numbers in parentheses indicate sample period, in days, over which collections were made.

Note that converting from particle concentration in mg/l to kg/ha/yr simply requires multiplying concentration values by the conversion factor C, where

$$C = r(ml/mm) \times 10^{-3}(l/ml) \times \rho(mm/yr) \times 10^{4}(m^2/ha) \times 10^{-6}(kg/mg) \times a^{-1}(m^{-2})$$

where ρ is the yearly rainfall rate and a is the collection container area of 0.0511 m^2. C needs to be determined for each site, since ρ differs.

TABLE 8

Ionic concentrations in rainwater from all collection sites

Collection date	$[Cl^-]/[SO_4^{2-}]$			
	Site 1	Site 2	Site 3	Site 4
18 Dec 85	17.1			
18 Dec 85	17.8			
19 Dec 85		18.5		
27 Dec 85	19.1	16.2		
29 Dec 85	19.2	18.3	18.2	
30 Dec 85	19.2	20.6	18.8	
31 Dec 85	19.0			
2 Jan 86	26.1	18.8	18.5	
3 Jan 86	18.4	14.3	12.5	
9 Jan 86	19.4	17.1	16.7	
13 Jan 86	18.0	16.1	16.4	
17 Jan 86	17.8			
18 Jan 86		16.8		
1 Feb 86	19.4			
2 Feb 86		18.4		
6 Feb 86	18.2			
7 Feb 86			17.0	
11 Feb 86	18.8	17.7		
13 Feb 86				17.8
23 Feb 86	19.1	17.7		15.7
3 Mar 86	18.9			
4 Mar 86		19.6		
7 Mar 86	19.6			
9 Mar 86	20.0			
10 Mar 86	20.4			
16 Mar 86		19.4		
25 Mar 86	19.9			
29 Mar 86	19.8	21.2		
3 Apr 86		19.0		
8 Apr 86	19.3			
9 Apr 86	19.4	19.4		

TABLE 9

NaCl concentration in individual water samples for all collection sites

Collection date	Equivalent NaCl deposited in rain (mg/l)			
	Site 1	Site 2	Site 3	Site 4
18 Dec 85	35.4			
	34.8			
19 Dec 85		40.4		
27 Dec 85	238.0	55.4		
29 Dec 85	88.8	49.8	36.2	
30 Dec 85	66.9	28.6	37.6	
31 Dec 85	645.8			
2 Jan 86	292.2	74.7	81.4	
3 Jan 86	27.9	6.2	6.5	
9 Jan 86	173.2	34.4	40.6	
13 Jan 86	68.1	32.3	31.6	
17 Jan 86	51.6			
18 Jan 86		25.5		
1 Feb 86	290.4			
2 Feb 86		118.6		
6 Feb 86	91.3			
7 Feb 86			50.9	
11 Feb 86	562.7	83.2		
13 Feb 86				72.1
23 Feb 86	93.8	43.4		18.6
3 Mar 86	50.2			
4 Mar 86		22.4		
7 Mar 86	455.0			
9 Mar 86	901.3			
10 Mar 86	123.8			
16 Mar 86		99.0		
25 Mar 86	595.0			
29 Mar 86	939.0	391.0		
3 Apr 86		33.4		
8 Apr 86	118.6			
9 Apr 86	185.0	85.6		

Table 7 lists mean NaCl concentrations for various sites of rainwater samples spanning concurrent periods of time. The collection date and site and percentage difference of [NaCl] with respect to site 1 are also given. Note that, on average, the percentage difference and standard deviations of [NaCl] between sites 1 and 2, and sites 1 and 3 are (61%, 16.5%) and (68.8%, 13.1%) respectively. Site 1 has consistently higher NaCl concentrations than sites 2 and 3. This is to be expected anyway, because the scavenging coefficient, A, decreases with increasing altitude since it is directly proportional to the vertical sea-salt concentration, as shown in table 5.

If n_x is now replaced by $n_x' = (n_A+n_B+n_C)/3$ and a recalculation of Q_M is made, then a more accurate theoretical estimate of Q_m can be made, based on a better estimate for n. n_x' is taken to be the mean NaCl particle concentration over site 1, averaged over regions A, B and C, a simple assumption which later proves to be a good estimate. Let Q_m' stand for this new theoretical estimate, which can be simply found from

$$Q_m' = Q_m(n_x'/n_x)$$

Q_m' and n_x' become equal to 1441 kg/ha/yr and 619 cm^{-3} respectively. Q_m' is now the new theoretically derived value of NaCl deposition rate in

precipitation at site 1. It will be demonstrated in the next section that this compared favourably with actual measurements.

RESULTS

Unfortunately, due to an unknown and unspecified problem with the chemical analysis of rainwater, it was not possible to obtain consistent [Na^+] values. However, [Cl^-] and [SO_4^{2-}] values were successfully determined. To demonstrate whether NaCl deposited in precipitation is marine derived, the ratio [Cl^-] to [SO_4^{2-}] was calculated and compared to the known ratio for seawater, a constant ratio of 19.3 (Millero 1974). Table 8 lists recovery dates, collection sites and the ratio [Cl^-] to [SO_4^{2-}] for all water samples used in the ensuing analysis. For sites 1, 2 and 3 the mean [Cl^-] to [SO_4^{2-}] ratio and standard deviation values are (19.3, 1.7), (18.2, 1.7) and (16.9, 2.1) respectively. Sulphates being of a higher molecular weight would be expected to have a different scavenging coefficient dependence with altitude. In fact, the trend appears to be that the ratio [Cl^-] to [SO_4^{2-}] decreases with increasing altitude. However, the result appears to be consistent with Evans' (1970), Jenkin's (1972) and Croome's (1984) conclusions, in that NaCl, at least, is marine derived in precipitation over Macquarie Island. Table 9 lists date, collection site and [NaCl] for each sample collected. Much variability in concentration is evident and is directly attributed to local weather conditions, such as humidity and wind speed. This variability is not examined in this study, as not enough is known about these conditions at sites 2, 3 and 4. Mean values of [NaCl], as collected for each site, are listed in table 10 along with the equivalent deposition rate for NaCl.

It was calculated by Evans (1970) that 24 000 kg/ha/yr of NaCl are deposited in precipitation over site 1, and similarly 7999 and 565 kg/ha/yr of NaCl over site 2 and site 3 respectively, by Jenkin (1972). These amounts for sites 1 and 2 are in gross disagreement with those obtained in the present study. This discrepancy is either due to inaccurate chemical analysis or faulty collection procedures. For example, Evans does not describe the procedure used in decanting rainwater samples, nor if they were fixed against degradation. It is quite possible that either too few samples were collected and/or analysed or that too many rain events occurred before a collection was made. Averaging of [NaCl] for too few rainwater samples may indeed have revealed such a high deposition rate. The variability in measured deposition rates in this study has been shown to be quite high, but it is not high enough to account for a tenfold variation in Evans' data for site 1. If a collection container is left unserviced for a long time it is quite possible that some evaporation of water can occur, due to wind and sun action; also dry salt particles can attach themselves to the collection container during non-precipitation

TABLE 10

Mean NaCl concentration from all samples for each collection site and their equivalent deposition rates, along with previously determined deposition rates by Evans (E) and Jenkin (J)*

Collection site	Number of rainwater collections	[NaCl] (mg/l)	Calculated deposition rate of NaCl (kg/ha/yr)	
			Mallis	Evans and Jenkin
1	23	266.5 (279.5)	2423 (2539)	24 016 (E) [13]
2	17	72.0 (87.6)	654.5 (798)	7999 (J) [66]
3	7	40.7 (22.5)	370 (205)	565 (J) [50]
4	2	45.4 (–)	413 (–)	630 (E)

* Numbers in square brackets give the known number of continuous days over which rainwater was collected. Parentheses contain the standard deviation of the mean. No standard deviations are given for site 4, because only two samples were collected, and so no statistical significance could be claimed.

periods. Either possibility, or a combination, can lead to unrealistically high levels of NaCl; hence, in the present study, the collection of rainwater samples every few days from all sites. Thus, it is claimed that data collected by the present study and listed in table 10 are much more representative of actual deposition rates than Evans' and some of Jenkin's data. Evans' data are also questionable on the grounds that Millero (1974) gives average world seawater [NaCl] as 30 120 mg/l. This compares with 2674 mg/l from Evans' data for site 1, which is some 9% of that of seawater. This figure seems quite large and unrealistic.

CONCLUSION

As a result of the present studies, it is claimed that deposition of scavenged airborne NaCl particles over Macquarie Island in precipitation is almost entirely due to dry sea salt and not sea spray. Although it cannot be explicitly proven that this finding is valid, it is encouraging that the theoretically predicted deposition rate of 1441 kg/ha/yr falling on site 1 is 60% of that actually recorded, namely 2423 kg/ha/yr. Considering that the observed standard deviation was 2539 kg/ha/yr, the theoretically derived value seems an acceptable figure. It appears that Evans' (1970) and Jenkin's (1972) data previously contributed to false inferences regarding NaCl scavenging. It is now concluded that scavenging of airborne (dry) NaCl particles can alone successfully account for the total NaCl deposited due to in- and below-cloud scavenging over Macquarie Island, and there is no need to suppose that scavenging of sea spray is responsible for any major component of the total salt budget. Experimental data, collected to test previous theoretical calculations made of this problem, seem to verify the above conclusion.

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REFERENCES

CRANDALL, W.K., MOLENKAMP, C.R., WILLIAMS, A.L., FULK, M.M., LANGE, R. & KNOX, J.B., 1973: *Res. Rep. UCRL–75896*. . Lawrence Livermore Laboratory, California.

CROOME, R., 1984: Limnological studies on Macquarie Island. *Tasm. Nat.*, 78: 26–27.

EVANS, A.J., 1970: Some aspects of the ecology of a calanoid copepod, *Pseudoboeckella brevicaudata* Brady 1875, on a subantarctic island. *ANARE Rep.*, 110.

JENKIN, J.F., 1972: Studies on plant growth in a subantarctic environment. Unpublished Ph.D. thesis, University of Melbourne.

MALLIS, M., 1985: A qualitative investigation into scavenging of airborne sea salt over Macquarie Island. *ANARE Res. Notes*, 26.

MILLERO, F.J., 1974: The physical chemistry of seawater. *Ann. Rev. Earth Planet. Sci.*, 2: 101–150.

PRUPPACHER, H.R. & KLETT, J.D., 1980: *MICROPHYSICS OF CLOUDS AND PRECIPITATION*. D. Reidel, Holland.

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MACQUARIE ISLAND FLORA AND FAUNA MANAGEMENT — INTERPRETING PROGRESS AND PREDICTIONS FOR THE FUTURE

by N.P. Brothers and G.R. Copson

(with three tables and two text-figures)

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The flora and fauna of Macquarie Island, in the subantarctic, have been experiencing a gradual but sure deterioration since the introduction of alien species. The greatest single achievement in attempts to stop this has been success with controlling the European rabbit (*Oryctolagus cuniculus*). The actual impact of rabbit control on other introduced species causing ecological damage has far exceeded expectations. Plant communities diminished by 100 years of rabbit grazing are re-establishing rapidly. Because of the success with controlling rabbit numbers, total elimination of feral cats (*Felis catus*) and wekas (*Gallirallus australis*) can be achieved, with the major potential benefit being the recovery of some seabird populations which are all but extinct on the main island. However, unless the effort given to these and other management problems discussed can be maintained until completion, the progress made will be rapidly lost and greater ecological problems could result.

Key Words: flora and fauna management, rabbit control, feral cats, wekas, Macquarie Island.

INTRODUCTION

Macquarie Island, in the subantarctic, is a Nature Reserve under the Tasmanian National Parks and Wildlife Act 1970. The reserve provides a first-class example of an island with native flora and fauna that have been severely affected by the thoughtless introduction of alien species, a problem common to many subantarctic islands (Jenkin *et al.* 1981, Clark & Dingwall 1985). Some of the changes resulting from these introductions have been in progress for 150 years, potentially sufficient time for any influences to have stabilised. With present attitudes favouring the reversal of changes caused by such introductions, an important consideration must be whether intervention is warranted and what it will achieve. The consequences of intervention are not always certain but fortunately the right course to rectify ecological damage on Macquarie Island was taken. In 1919, a major turning point in conservation on Macquarie Island came about, when 110 years of intensive commercial exploitation of seals and penguins for their oil or fur was terminated (Cumpston 1968). From this time on, the island has been recognised as worthy of protection from disturbance by man (Mawson 1922), this protection being legally declared since 1933 (Anon 1987).

All current management problems and attempts to solve them are closely linked to the introduction of the European rabbit (*Oryctolagus cuniculus*), which has been recognised as having caused the greatest modifications to Macquarie Island's ecology. The Tasmanian National Parks and Wildlife Service (TNPWS) involvement in Macquarie Island management commenced in 1972, at which time rabbits were already considered detrimental to the island (Taylor 1955, Costin & Moore 1960). Determining the extent of damage, and attempting to predict the effects of rabbit control on native flora and fauna, before control was initiated, were priorities for the following six years.

This work substantiated earlier observations of researchers that steps would have to be taken to ensure survival and recovery of certain native flora and fauna on Macquarie Island. Hence, in 1978, TNPWS moved into the second phase of pest species control and associated monitoring of resulting changes. With this, the effort to document the ecology of species, other than rabbits, considered relevant to management problems proved invaluable not only for planning control programmes but for assessing progress. This work is continuing at present.

RESEARCH AND MANAGEMENT PROGRESS

Rabbits

First introduced in the 1870's as food for sealers (Cumpston 1968), rabbits became established over the whole of Macquarie Island in varying densities, dependent upon habitat, with a weather-induced fluctuating population of between 50 000 and 150 000 (Copson *et al.* 1981). Although the decision to control rabbit numbers was taken in the mid-1960's, it was then based on general observations of destruction to vegetation and soils.

Data to prove that control of rabbits was warranted were gathered in an intensive programme between 1972 and 1978. While this work was underway, progress continued with establishing the European rabbit flea (*Spilopsyllus cuniculi*) (Skira *et al.* 1983), the vector necessary for the disease, myxomatosis, that had been determined, in 1968, as the only suitable method of controlling rabbits on Macquarie Island (G.C. Johnston, unpublished report). By 1978, investigations had determined that rabbit control was necessary and, as rabbit fleas had finally become sufficiently established, myxoma virus was introduced (Brothers *et al.* 1982). Since this first introduction of myxomatosis, a campaign of virus introduction has continued over the whole island each austral spring and summer, with the effects being monitored at standard count areas (table 1). By 1986, rabbit numbers had been reduced by about 80% to approximately 15 000, most of this being achieved in the first three to four years. Caroline Cove and Hurd Point count area figures (table 1) demonstrate the slow progress in rabbit control experienced in some areas, due to low flea abundance, but consistently low counts for four or more years at most other count areas indicate the ability to keep rabbit numbers at a reduced level.

To have arrived, in 1986, at a point where rabbit numbers had been reduced to an environmentally acceptable level, with still further potential for reduction, was a major achievement, given the difficulties encountered with the work. Because of unfavourable weather conditions and the ecology of Macquarie Island rabbits, it took ten years and the release of 241 600 fleas (Skira *et al.* 1983) before these were well enough established to proceed with control using myxomatosis. Fleas from wild rabbits are still being transferred to pockets of rabbits where fleas are absent.

Problems in inoculating rabbits with myxoma virus had to be overcome. Initially, live trapping was used to obtain rabbits, averaging two animals per man day. The redevelopment of a "dart gun" (Brothers 1982) increased the inoculation rate to an average of 30 rabbits per man day. Using this technique of inoculation permits indefinite control over the whole island with minimal effort.

The long-term viability of myxoma virus for rabbit control on Macquarie Island is dependent on a number of factors. Indications are that all the

TABLE 1

Rabbit Numbers at Standard Count Areas on Macquarie Island, 1974–86*

Count area	Mean number of rabbits										
	1974	1975	1976	1978	1979	1980	1981	1983	1984	1985	1986
NW Square Lake	2.9	6.0	10.4	15.7	5.1	0	1.0	0.7	0.7	0	4.0
S Square Lake	16.4	36.5	39.6	66.4	8.9	16.4	26.0	4.7	16.9	0.6	12.0
Red River	29.3	44.4	43.6	81.4	17.1	6.0	9.0	0.6	2.6	2.9	0.6
Prion Lake	15.0	14.7	18.0	35.4	40.8	41.3	42.0	4.8	6.4	1.0	2.6
Green Gorge I	23.0	19.0	29.0	33.1	25.3	23.5	9.5	0.8	0.8	3.3	1.0
Green Gorge II	15.3	18.4	26.6	34.0	35.2	33.5	15.0	1.0	1.5	2.0	0
Cormorant Point		9.6	14.9	68.4	8.5	0.7	0	0.6	2.5		5.0
Aurora Point		12.4	15.1	56.2	50.9	40.3	1.5	5.0	4.0		
Caroline Creek	8.0	10.9	22.0	20.0	13.0	25.0		17.0	17.6	26.2	7.9
Hurd Point	13.3	15.3	16.5	8.0	13.0			10.0	21.2	20.0	9.1
Yearly mean of all counts	15.4	18.7	23.6	41.9	21.8	20.7	13.0	4.5	7.4	7.0	4.7

* Ten two-hectare count areas were monitored. Counts were usually made monthly in most years from 1974 to 1986 (myxoma virus introduced in 1978) and are continuing. (Brothers *et al.* 1982.)

TABLE 2

Comparison of Flea Infestation in Rabbits on Macquarie Island Before and After* Introduction of Myxoma Virus in 1978

Sampling period	Number of rabbits sampled	Flea abundance						Totals	
		1–4	%	5–20	%	>20	%	Rabbits with fleas	%
Before myxoma virus	5141	762	15	818	16	415	8	1995	39
After myxoma virus	981	400	41	229	23	111	11	740	75

* Sample period 1985–86.

factors discussed in Brothers *et al.* (1982) are favourable. It was uncertain whether fleas would persist in the rabbit population following epizootics, and the presence of fleas is critical for effective control of rabbits on Macquarie Island with myxomatosis. Table 2 compares flea abundance in the rabbit population before and after myxomatosis, and a significant increase in flea abundance is apparent.

Feral Cats

The presence of feral domestic cats (*Felis catus*) since about 1820 on Macquarie Island (Debenham 1945) has caused a considerable reduction in populations of indigenous fauna (Taylor 1979, Brothers 1984). The Australian Antarctic Division initiated a study of feral cats on the island in 1974 (Jones 1977) and studies were continued by TNPWS (Brothers *et al.* 1985). The conclusions of these studies were that up to 500 cats occur scattered over the whole island, mostly in herbfield or tussock grassland. Seasonal food availability controls the size of the population, there being a great dependence on rabbits since burrow-nesting petrels were preyed upon to such an extent that species diversity and abundance are now low.

In the ten years since 1976, a total of 522 cats has been destroyed by live trapping, shooting and gassing in burrows. Serious efforts to eradicate cats did not commence until 1985, although the decision to proceed with eradication was made by TNPWS in 1983, when rabbit control was having a noticeable impact on cat abundance due to food shortages that it created. It is not possible, at this stage, to assess the impact of eradication measures, as interpreting data is complicated by the use of varying techniques and effort expended on eradication. No obvious alteration is apparent in such aspects as age structure of the cat population (fig. 1) that may have been brought about by a high proportion of the population being removed. The percentage of cats sampled has remained the same with respect to coat colour, but the sex ratio of these cats now favours females, which may be an early indication of progress with population reduction (table 3). There is no doubt, however, that the effort required in 1980 to kill 112 cats was substantially less than that expended in 1985 and 1986 for a similar result. Trapping, shooting and gassing of cats in an effort to achieve eradication is continuing.

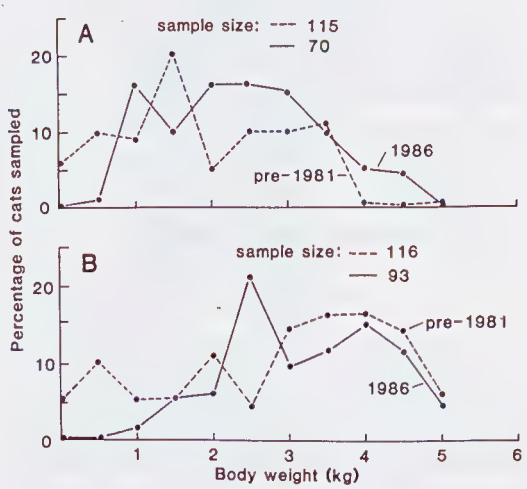

FIG. 1 — Comparison between pre-1981 (----) and 1986 (——) percentages of (A) female and (B) male cats sampled on Macquarie Island, in body weight intervals of 500 g.

TABLE 3

Sex Ratio and Coat Colour of Feral Cats Sampled on Macquarie Island

Year	Sample size		Sex ratio	Coat colour		
	F	M		Ginger	Tabby	Black
Before 1981	109	137	M 1:0.8	26%	74%	2%
1984	31	41	M 1:0.8	19%	82%	1.9%
1986	70	57	F 1:0.8	27%	71%	1.4%

Wekas

The weka (*Gallirallus australis*), introduced to Macquarie Island in the 1870's from Stewart Island (Cumpston 1968), is thought to have played a major role in the destruction of burrow-nesting petrel populations (Brothers 1984) and in the extinction of two endemic birds (Taylor 1979). In recent times the impact of wekas on petrels has not been great, because they are largely confined to coastal tussock grassland where few petrels now remain (Brothers 1984, Brothers & Skira 1984). The necessity to eradicate wekas became apparent in 1978 but, prior to embarking on a programme of intensive eradication in 1985, aspects of their ecology were studied during 1979 (Brothers & Skira 1984). As early as 1980, there were obvious signs that the island's population of about 500 wekas had decreased significantly. In 1976 the total number of weka sightings was 326 and in 1979 it was 232 (98 of which were shot). Only 11 were seen in 1984, and 22 of 23 seen in 1986 were either trapped or shot. This rapid decrease in the weka population is thought to be largely due to increased cat predation as their chief food source, rabbits, were reduced in numbers by myxomatosis. At present, wekas are rarely seen anywhere except at the northern tip of the island. All animals encountered are being shot or trapped and eradication of this pest is imminent.

Vegetation

Although the extent to which rabbits influence erosion patterns on the island has yet to be clearly defined, there is good documentation with regard to their influence on vegetation. Throughout the whole period of the TNPWS involvement with management of Macquarie Island, studies of the vegetation have been carried out, with emphasis on long-term monitoring of changes due to the presence or, more recently, absence of rabbits. Copson (1984) summarised the relationship between rabbits and the vascular flora. Of the 45 species of vascular plants now recorded from the island (Seppelt *et al.* 1984), only 41 were identified prior to rabbit control; seven of the 41 species were never grazed by rabbits, two species suffered badly and 19 species benefited by the presence of rabbits. Of the 21 species listed as rare, 12 were grazed by rabbits and two of these were adversely affected (Copson 1984).

It is estimated that about 50% of present herbfield will revert to tussock grassland (fig. 2), in response to the severe reduction in rabbit numbers. This will bring about dramatic changes in the distribution and abundance of many species of plants. Species such as the tussock grass *Poa foliosa* and the herb *Stilbocarpa polaris* will thrive, to the detriment of most of the 19 species that have benefited by the presence of rabbits. These changes are already, in the eight years since myxomatosis was introduced, very evident and are being monitored regularly at a number of permanent study sites.

General

Preventing any further introductions of potentially serious pest species to the island is an area of management that is of great concern. Informal arrangements with the Australian Antarctic Division over quarantine are being developed and implemented at present.

Some species have received attention in ongoing studies because they are considered vulnerable. Wandering albatrosses (*Diomedia exulans*), black-browed albatrosses (*D. melanophris*) and grey-headed albatrosses (*D. chrysostoma*) are all rare (Tomkins 1985, Copson, this volume). Subantarctic fur seals (*Arctocephalus gazella*) and antarctic fur seals (*A. tropicalis*) are breeding in very low numbers on Macquarie Island (Shaughnessy *et al.*, this volume) and these populations are being closely monitored. Brothers (1984) identified burrow-nesting petrels that are rare and

vulnerable. Because of the status of all these species, TNPWS does not permit any research on them that may cause disturbance, particularly to breeding success. Protection from research causing intervention is also extended to some rare plants on the island.

In addition to controlling disturbance by scientists, measures have also been taken to reduce the effects of other visitors. A handbook has been prepared to provide general guidelines to intending visitors (Anon 1987). Relocating walking tracks to avoid areas more sensitive to disturbance is an ongoing activity. In some habitats, a footprint may remain visible for 20 years or more. Recently it was decided by TNPWS that it would be necessary to close a section of the island to human access for part of the year, to reduce disturbance to the few wandering albatrosses that remain. This action can be applied to other species and/or historical locations, if it is considered necessary.

MANAGEMENT REQUIREMENTS AND PREDICTIONS FOR THE FUTURE

A major problem with interpreting management progress and monitoring population trends of species on Macquarie Island has been the absence of adequate comparative information on earlier population sizes and distributions. Survey work to establish distribution and numbers is often not given priority, the tendency being to step straight into much narrower fields of research. Apart from studies of species with specific management requirements already discussed, there have been recent attempts to define population sizes and distribution of other species on the island, for example, king penguins (*Aptenodytes patagonicus*) (Rounsevell & Copson 1982), king shags (*Phalacocorax albiventer purpurascens*) (Brothers 1985), gentoo penguins (*Pygoscelis papua*) (Robertson 1986), royal penguins (*Eudyptes schlegeli*) (Copson & Rounsevell 1987). These studies will provide essential baseline information for management, for which re-assessment of these populations in the future will also be required.

If present management objectives of feral cat and weka eradication and maintained control of rabbits are achieved, recolonisation and expansion of burrow-nesting petrels, along with a return of natural plant communities, are likely to occur. Several interesting interactions of other species with these changes are predicted, some of which may be to a certain extent detrimental. Ship rats

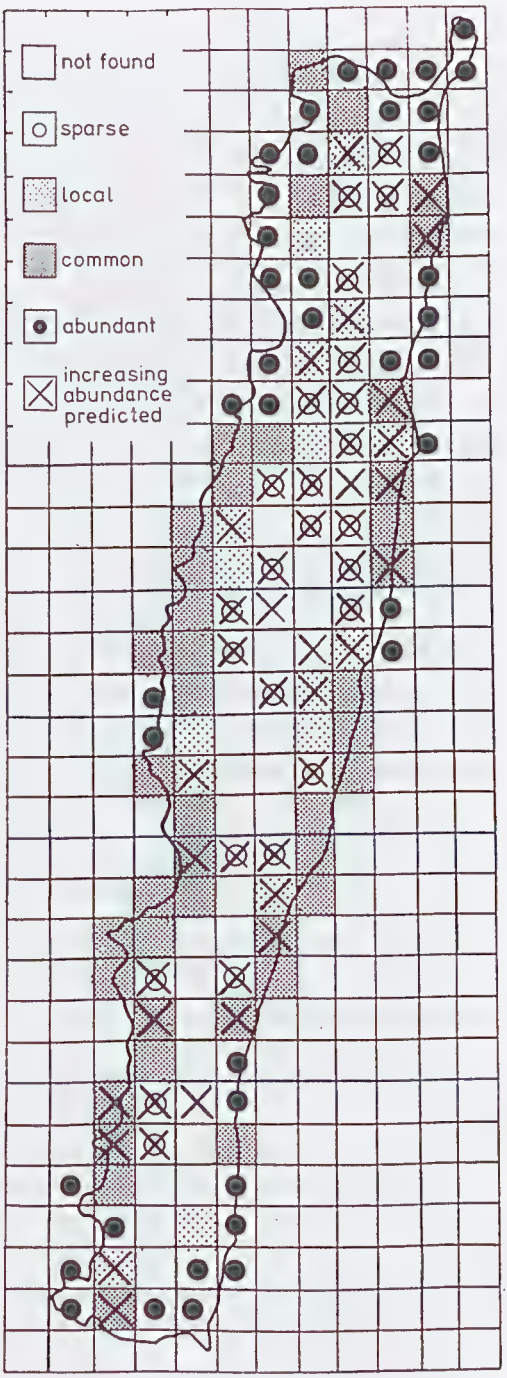

FIG. 2 — Distribution of the tussock grass Poa foliosa *on Macquarie Island (Copson 1984).*

(*Rattus rattus*), introduced to the island late in the last century (Cumpston 1968), are associated only with the tussock grassland (G.R. Copson, unpublished data). In response to the spread of tussock grassland, they will have access to large areas where they are unable to exist at present. In his study of the rats' diet in 1978, Copson (1986) did not substantiate the observation of Brothers (1984) that rats eat burrowing petrels, because, at present, rat predation on petrels is localised, very seasonal, and therefore difficult to detect. The impact of rats on burrowing petrels may be substantial in the future, as they will have access to smaller species of petrels, through expansion of tussock grassland into existing petrel colonies and recolonisation from offshore stacks of species formerly widespread in tussock grassland (Brothers 1984). Provided recolonisation and expansion of petrel populations can be accelerated by eradication of their main predators, cats and wekas, these populations should be able to withstand rat predation in the long term.

There has already been a noticeable change in the breeding distribution of the great skuas (*Stercorarius skua lonnbergi*) in response to rabbit control (Skira 1984). The abundance of rabbits for food enabled skuas to breed over a wide area of the island and their predation on petrels was high because of this. With rabbits in short supply, skuas have been forced to concentrate nesting territories closer to other food sources, such as penguin colonies. Their predation on burrowing petrels has therefore decreased and will presumably decrease further as regrowth of tussock grassland affords greater protection to the petrels.

Eradication of cats and wekas must be achieved rapidly before tussock grassland and burrowing petrels recolonise substantially. Cats will keep weka numbers in check for as long as the rabbit population is controlled. But, once burrowing petrel populations increase, so too will cats and wekas, and predation by these, coupled with that of rats, may have an even greater impact on petrel populations than any seen on the island so far.

Financial constraints on, and priority allocation of TNPWS work constantly threaten the continuation of the work on Macquarie Island. To abandon the present wildlife managment programmes will mean that 15.5 man years, representing approximately 50 000 km of walking to carry out field programmes, will have been all but wasted, given the above predictions. Present efforts must be sustained or intensified, until eradication of cats and wekas is achieved. The need to maintain indefinite control of rabbit numbers, so their impact on flora is kept at an acceptably low level, must also be recognised. This control will require comparatively little effort and, if the opportunity arises through new techniques, eradication of rabbits may become possible in the future.

A management plan for Macquarie Island Nature Reserve is essential for proper long-term protection. However, unless serious consideration is given to extending some form of protection to the waters around the island, protection of the island itself may be of little long-term value, since all indigenous vertebrates on the island are totally reliant for their survival on marine food resources, which they are now having to share ever increasingly with humans.

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REFERENCES

ANON, 1987: *MACQUARIE ISLAND NATURE RESERVE: VISITOR'S HANDBOOK*. National Parks and Wildlife Service, 48 p.

BROTHERS, N.P., 1982: A simple and efficient method of administering myxoma virus. *In* WARNER, H.K., FARRER, K.T.H. & WHITTON, W.I. (Eds): *Innovations in Australian Technology 1980–81*, 6: 20. Australian Academy of Technical Science.

BROTHERS N.P., 1984: Breeding, distribution and status of burrow-nesting petrels at Macquarie Island. *Aust. Wildl. Res.*, 11: 113–131.

BROTHERS, N.P., 1985: Breeding biology, diet and morphometrics of the King Shag, *Phalacrocorax albiventer purpurascens*, at Macquarie Island. *Aust. Wildl. Res.*, 12: 81–94.

BROTHERS, N.P., EBERHARD, I.E., COPSON, G.R. & SKIRA, I.J., 1982: Control of rabbits on Macquarie Island by myxomatosis. *Aust. Wildl. Res.*, 9: 477–485.

BROTHERS, N.P. & SKIRA, I.J., 1984: The Weka on Macquarie Island. *Notornis*, 31: 145–154.

BROTHERS, N.P., SKIRA, I.J. & COPSON, G.R., 1985: Biology of the Feral Cat, *Felis catus* (L.), on Macquarie Island. *Aust. Wildl. Res.*, 12: 425–436.

CLARK, M.R. & DINGWALL, P.R., 1985: *CONSERVATION OF ISLANDS IN THE SOUTHERN OCEAN: A REVIEW OF THE PROTECTED AREAS OF INSULANTARCTICA*. IUCN.

COPSON, G.R., 1984: An annotated atlas of the vascular flora of Macquarie Island. *ANARE Res. Notes*, 18.

COPSON, G.R., 1986: The diet of the introduced rodents *Mus musculus* L. and *Rattus rattus* L. on subantarctic Macquarie Island. *Aust. Wildl. Res.*, 13: 441–445.

COPSON, G.R., 1988: The status of the black-browed and grey-headed albatrosses on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 137–141.

COPSON, G.R., BROTHERS, N.P. & SKIRA, I.J., 1981: Distribution and abundance of the rabbit, *Oryctolagus cuniculus* (L.) at subantarctic Macquarie Island. *Aust. Wildl. Res.*, 8: 597–611.

COPSON, G.R. & ROUNSEVELL, D.E., 1987: The abundance of Royal Penguins (*Eudyptes schlegeli*, Finsch) breeding at Macquarie Island. *ANARE Res. Notes*, 41.

COSTIN, A.B. & MOORE, D.M., 1960: The effects of rabbit grazing on the grasslands of Macquarie Island. *J. Ecol.*, 48: 729–732.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1).

DEBENHAM, F. (Ed.), 1945: THE VOYAGE OF CAPTAIN BELLINGHAUSEN TO THE ANTARCTIC SEAS, 1819–1921. Transprinted by Hakluyt Society.

JENKIN, J.F., JOHNSTONE, G.W. & COPSON, G.R., 1981: Introduced animal and plant species on Macquarie Island. Colloque sur les Ecosystemes Subantarctique, Paimont, 1981. *CNFRA*, 51: 301–313.

JONES, E., 1977: Ecology of the feral cat, *Felis catus* (L.), (Carnivora:Felidae), on Macquarie Island. *Aust. Wildl. Res.*, 4: 249–262.

MAWSON, D., 1922: Macquarie Island and its future. *Pap. Proc. R. Soc. Tasm.*, 1922: 39–54.

ROBERTSON, G., 1986: Population size and breeding success of the Gentoo Penguin, *Pyposcelis papua*, at Macquarie Island. *Aust. Wildl. Res.*, 13: 583–587.

ROUNSEVELL, D.E. & COPSON, G.R., 1982: Growth rate and recovery of a King Penguin, *Aptenodytes patagonicus*, population after exploitation. *Aust. Wildl. Res.*, 9: 519–525.

SEPPELT, R.D., COPSON, G.R. & BROWN, M.J., 1984: Vascular flora and vegetation of Macquarie Island. *Tasm. Nat.*, 78: 7–13.

SHAUGHNESSY, P.D., SHAUGHNESSY, G.L. & FLETCHER, L., 1988: Recovery of the fur seal population at Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): xx–xx

SKIRA, I.J., 1984: Breeding distribution of the Brown Skua on Macquarie Island. *Emu*, 84(4): 248–249.

SKIRA, I.J., BROTHERS, N.P. & COPSON, G.R., 1983: Establishment of the European Rabbit Flea on Macquarie Island. *Aust. Wildl. Res.*, 10: 121–127.

TAYLOR, B.W., 1955: The flora, vegetation and soils of Macquarie Island. *ANARE Rep.*, Ser. B(II), 19.

TAYLOR, R.H., 1979: How the Macquarie Island Parakeet became extinct. *N.Z. J. Ecol.*, 2: 42–45.

TOMKINS, R.J., 1985: Reproduction and mortality of Wandering Albatrosses on Macquarie Island. *Emu*, 85(1): 40–42.

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THE STATUS OF THE BLACK-BROWED AND GREY-HEADED ALBATROSSES ON MACQUARIE ISLAND

by G. R. Copson

(with one table)*

COPSON, G.R., 1988 (viii): The status of the black-browed and grey-headed albatrosses on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 137–141. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Lands, Parks and Wildlife, Hobart, Tasmania, Australia 7000.

Marginal populations of both black-browed (*Diomedea melanophris*) and grey-headed (*D. chrysostoma*) albatrosses breed in the Macquarie Island Nature Reserve. Black-browed albatrosses breed in three colonies: one, on North Head, has been declining in numbers since the 1950's; the second, in the southwest corner of the island, has been increasing; the third, on Bishop and Clerk Islets, appears to be larger than the second. Breeding success has been high in the southwest colony over the past ten years, but recruitment of banded youngsters into the breeding population has been very low.

Grey-headed albatrosses, biennial breeders, breed only in the southwest corner of the island, with an apparently stable breeding population. The breeding success is slightly higher than that of the black-browed albatrosses but again recruitment into the breeding population is very low.

First breeding records of birds banded as fledglings are given for both species and these data are used to extrapolate minimum ages for birds banded as adults in the 1950's. Observations from several seasons are combined to construct the breeding cycles of both species at Macquarie Island Nature Reserve.

Key Words: black-browed albatross, grey-headed albatross, breeding cycles, marginal populations, Macquarie Island.

INTRODUCTION

The first account of albatrosses at Macquarie Island was by Bellinghausen, the Russian explorer, who visited there in November 1820. He recorded albatrosses being on eggs, and that the sealers were using them as food, but did not record which species (Debenham 1945). Captain Raine (1824) also recorded seeing albatrosses (without mentioning the species) and reported that the sealers were supplementing their rations with young albatrosses, amongst other things. Burton, who was a taxidermist and spend three and a half years on the island in the 1890's, recorded only two albatrosses, the royal and the sooty (Cumpston 1968).

In December 1912, Hamilton collected an albatross from the southwest corner of the island which he identified as a grey-headed albatross, but Falla could not trace this specimen and left the identification open (Falla 1937). During the second season (1930–31) of the British Australian New Zealand Antarctic Research Expedition (BANZARE), mature black-browed albatrosses were plentiful off Macquarie Island but never more than one grey-headed albatross per day was seen in the same area (Falla 1937).

At the present time, black-browed albatrosses breed in three localities in the reserve, the western side of North Head, the southwestern side of Petrel Peak, and Bishop and Clerk Islets, 37 km south of Macquarie Island. Grey-headed albatrosses only breed on the southern and southwestern flanks of Petrel Peak and there are no records of their having bred in other areas of the reserve.

STUDY AREAS AND METHODS

The colonies of black-browed albatrosses, both at North Head and on the southwestern flank of Petrel Peak, have been studied intermittently since 1949. Grey-headed albatrosses have been studied since 1952 in the reserve, but again only intermittently. Since 1975, work has been carried out on both species in the colonies of the southwestern corner of the reserve. For this paper, data for the years prior to 1976 were obtained from Australian National Antarctic Research Expedition (ANARE) logs and Australian Bird and Bat Banding Schemes (ABBBS) banding schedules.

The current study has been carried out by the National Parks and Wildlife Service from the 1976–77 season. Nests with eggs were marked with numbered stakes in October or November of each year (except for 1982 when the Service did not have

anybody overwintering on the island). In four of the seven years of the study, the area was visited again in December to identify as many breeding birds as possible. Hatching success was obtained from a visit in early January and the fledglings were banded in March or April. Breeding success is calculated only on data from the nests marked in October or November, although any other chicks found in subsequent searches were banded. A few chicks found to have died in the colony after banding were counted as not having fledged. Adult birds were banded on an opportunistic basis, but birds on eggs were not banded if they became agitated.

RESULTS

The combined observations from 1949–85 are incomplete and record only 25 breeding seasons. However, this still allows the construction of breeding timetables for both black-browed and grey-headed albatrosses.

Black-browed albatrosses begin to return to the reserve in the first week of September, the earliest date recorded being 3 September. Laying has been recorded as early as 26 September but most eggs are laid in early October. The dates at which the first chicks have been seen were 8 December 1980 and 10 December 1984. The chick recorded on 10 December was estimated to be 3–5 days old and two other chicks were also found to be chipping out of eggs on the same day. The peak of hatching is around the third week of December. Two birds were recorded as still being on eggs on 8 January but both were found to have failed by the next visit. The fledglings leave their nests from the second week of April.

On Macquarie Island, grey-headed albatrosses appear to conform to the biennial breeding pattern and there are no records of birds who have successfully bred one season returning to breed the next season. The first birds return to the island slightly later than black-browed albatrosses, the earliest sighting being on 13 September. Eggs are laid from the middle of October, the peak of laying being about the third week. Hatching commences in the latter half of December, the first records of chipping out being 20 December 1975 and 20 December 1983. Hatching is usually completed by the end of the first week of January. The chicks leave their nests from late April to the middle of May. There is one record of a fledgling still at the nest site on 5 June but it is not known whether it subsequently left the island.

In the 31 seasons from 1954–55 to 1984–85, at least 344 black-browed albatrosses (156 adults, 188 pullus) and 572 grey-headed albatrosses (284 adults, 288 pullus) have been banded on Macquarie Island. During this period, banding data are available for 20 seasons for black-browed and 16 seasons for grey-headed albatrosses.

Early ANARE records are incomplete and often difficult to interpret. The records for black-browed albatrosses breeding on North Head from the 1949–50 season to the 1961–62 season mention from 18+ to 31 pairs, 1+ to 16+ eggs laid and 1 to 14 chicks being fledged. Details of eggs laid, chicks hatched and chicks fledged are complete for only three seasons (1952–53, 12, 5 and 3; 1955–56, 11, 6 and 4; 1956–57, 12, 4 and 2). Over the same period, the sparse records for the southwestern colony give maximum figures of 10 nests (1956–57), 6 eggs (1960–61) and 1 chick fledged (1959–60). The records do not give complete data for eggs laid to chicks fledged for a single season.

The records for grey-headed albatrosses prior to the 1970's are even more sparse than those for black-browed albatrosses. ANARE logs record "about 100 birds", January 1950; "at least 60 on nests", October 1954; "44 nests were counted but no eggs", October 1955; "40 nests estimated", October 1957.

The present breeding population of black-browed albatrosses in the Macquarie Island Nature Reserve is estimated at between 60 and 80 pairs (North Head 2–3 pairs; southwestern corner 20–30 pairs; Bishop and Clerk Islets 25+ pairs (Mackenzie 1968) and 44+ pairs (Lugg *et al.* 1978)). The grey-headed albatross population is estimated at 80–100 breeding pairs and is confined to the southwestern corner of Macquarie Island.

The data for both black-browed and grey-headed albatrosses breeding in the southwestern study area during seasons 1977–78 and 1984–85 (excluding 1982–83) are given in table 1. Breeding success calculated from the study area data is 66.9% for black-browed albatrosses (range from 42.9% to 86.4%) and 72.3% (range 58.0% to 85.7%) for grey-headed albatrosses (table 1). Over this period the black-browed albatross colony at North Head produced no more than two eggs per season and no chicks fledged. The colony at North Head has decreased since the 1960's and the one at the southwestern corner of the island appears to have increased over the same period. Birds have been banded at both colonies (134 at North Head and 438 in the southwestern corner) but there are no records of banded birds having moved from one colony to the other.

TABLE 1

Breeding Success* of Black-browed and Grey-headed Albatrosses in Study Area on Macquarie Island**

Season	Eggs	Chicks		Breeding Success %
		hatched	fledged	
Black-browed Albatross				
1977–78	14	12	12	85.7
1978–79	27	15	13	48.1
1979–80	19	16	15	78.9
1980–81	21	11	9	42.9
1981–82	22	21	19	86.4
1982–83	no data			
1983–84	21	15	14	66.7
1984–85	21	16	15	71.4
x (±SD)				66.9±17.4
Grey-headed Albatross				
1977–78	28	25	24	85.7
1978–79	29	21	17	58.6
1979–80	30	27	22	73.3
1980–81	29	27	18	62.1
1981–82	44	38	36	81.8
1982–83	no data			
1983–84	31	18	18	58.0
1984–85	51	48	40	78.4
x (±SD)				72.3±11.5

* eggs laid to chicks fledged
** 1977–78 to 1984–85 seasons

The ages at which black-browed albatrosses banded as chicks were first resighted in the colony are three as five-year-olds, two as seven-year-olds and two as eight-year-olds. The two seven-year-olds and one eight-year-old were breeding when first resighted and one of the five-year-olds returned to breed as a seven-year-old. As no references have been found to black-browed albatrosses breeding at an earlier age, these seven-year-olds may represent the minimum breeding age for this species under the conditions found at Macquarie Island.

The record of the eight-year-old breeding was made in the 1985–86 season (the data are incomplete for this season and not included in table 1). If seven years old is taken as the minimum breeding age, the number of birds banded as chicks which could have returned to breed by the 1985–86 season is 120. The four birds above are the only ones recorded from chicks to breeding adults, which gives a minimum recruitment rate of 3.3%.

The oldest known age black-browed albatross was eleven years old when last sighted as a breeding bird in the 1984–85 season. Of birds first banded as adults, five were over 23 years old (taking seven years old as the minimum breeding age) the oldest being 29 years old when last sighted.

Seven grey-headed albatrosses banded as chicks have subsequently returned to the colony. One returned as a six-year-old, again as an eight-year-old and was recorded as breeding at ten years old. Another was first sighted as an eleven-year-old but it is not known whether it was breeding. The other five were first resighted as breeding birds, one each as seven-, eight- and nine-year-olds and two as ten-year-olds. To the end of 1978–79 season (i.e. seven years prior to the last season for which data are available) 152 chicks had been banded. This would give a minimum recruitment rate of 3.9%.

The grey-headed albatross first resighted as an eleven-year-old (above) is the oldest known aged bird from the colony. Five birds banded as

adults have subsequently been resighted in the colony 23 or more years later. If seven years old is taken as the minimum breeding age, these birds would have been at least 30, 33, 34 and two 36 years old when last sighted.

DISCUSSION

The breeding populations of black-browed albatrosses (60–80 pairs) and grey-headed albatrosses (80–100 pairs) in the Macquarie Island Nature Reserve are small compared with other breeding grounds. Elsewhere, estimates of breeding populations of black-browed albatrosses range from 200+ pairs at Heard Island (R. Ledingham, pers. comm.) up to 390 000 pairs on the Falkland Islands (Croxall *et al.* 1984); those for grey-headed albatrosses range from 1000 pairs in the Cape Horn region (Tickell 1976) to 38 000 pairs at South Georgia (Prince & Payne 1979).

The early records of black-browed albatrosses and grey-headed albatrosses at Macquarie Island give no indication of whether the present colonies are remnants of larger populations decimated by sealers and oil-gatherers in the last century or have re-established after being completely exterminated on the island during the commercial era. Alternatively, numbers may always have been small, or the population may have been established in the reserve only since around the turn of the century.

The grey-headed albatross population appears to have remained stable in the reserve since Hamilton discovered a colony of "not more than forty nests" in the southwestern corner of Macquarie Island in December 1912 (Falla 1937).

Black-browed albatrosses were first recorded breeding on Macquarie Island in the 1949–50 season, when both the North Head and south-western corner colonies were found. It appears very unlikely that these colonies would have been overlooked by members of AAE (1911–14) during their extensive fieldwork around the island. The colony on the Bishop and Clerk Islets was not discovered until 1965 (Mackenzie 1968). This may have been the source of recolonising birds on Macquarie Island, had populations there been exterminated by sealers. The only other colonies in the region are those on Campbell Island (700 km away), where both species breed. However, the black-browed albatrosses on Campbell Island are a subspecies *Diomedea melanophris impavida* and these have never been recorded at Macquarie Island.

Weimerskirch *et al.* (1986) showed that around Isles Crozet and Kerguelen *Diomedea melanophris* forages over the continental shelf, whereas *D. chrysostoma* range further afield to the colder subantarctic and antarctic waters. They also suggest a link exists between the size of a breeding population of *D. melanophris* and the extent of the continental shelf around the breeding site, i.e. the greater the extent of the continental shelf the larger the breeding population of black-browed albatrosses. If this is the case, Macquarie Island may never have supported a large breeding population of black-browed albatrosses, as it has virtually no continental shelf.

The breeding cycles of both species on Macquarie Island are similar to those of the birds breeding on Campbell Island, with black-browed albatrosses returning to the nesting sites and also laying approximately two weeks earlier than grey-headed albatrosses. Also, on the Falkland Islands black-browed albatrosses begin to return to their breeding colonies about the same time as those at Macquarie Island. In contrast, on South Georgia (Tickell & Pinder 1975) and Isles Crozet (Weimerskirch *et al.* 1986) grey-headed albatrosses return to their breeding colonies, and also lay their eggs, earlier than black-browed albatrosses.

A study of black-browed and grey-headed albatrosses at Bird Island, South Georgia, shows the breeding success (percentage of chicks fledged from eggs laid) to be lower for both species than at Macquarie Island. The results for Bird Island were black-browed albatrosses 37.8% ± 22.7 and grey-headed albatrosses 46.4% ± 12.9 (Prince 1985); for Macquarie Island the results were 66.9% > 17.4 and 72.3% ± 11.5 respectively. In both studies the breeding success of black-browed albatrosses varied more from year to year than that of grey-headed albatrosses. This may be due to black-browed albatrosses having more limited foraging grounds than grey-headed albatrosses (Weimerskirch *et al.* 1986), making them more susceptible to local fluctuations in their food supply. This is further supported by the two worst breeding seasons for black-browed albatrosses in the Bird Island study (1977–78, 11.4% and 1979–80 complete failure, Prince 1985) corresponding to breeding successes of 85.7% and 78.9% on Macquarie Island. Although minimum recruitment rates for both species have been given in the results, the data are insufficient to predict any long-term trends in these colonies.

In carrying out studies on marginal populations such as black-browed albatrosses on Macquarie Island, there is a problem of obtaining acceptable scientific results without causing permanent detrimental effects. The effects of studies must be balanced against the long-term benefits for

the species being studied, and the National Parks and Wildlife Service in its management of the reserve regulates the nature of proposed studies accordingly.

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The data presented in this paper have been collected by ANARE personnel over many years and I would like to thank them for their efforts. Errors of interpretation are mine. I would also like to thank the Tasmanian National Parks and Wildlife Service and the Antarctic Division of the Department of Science for making possible my stays on Macquarie Island. The Antarctic Division also made available the ANARE logs from 1948 to 1976. Australian Bird and Bat Banding Scheme supplied bird bands used in the study.

REFERENCES

CROXALL J.P., McINNES, S.J. & PRINCE, P.A., 1984: The status and conservation of seabirds at the Falkland Islands. *In* Croxall, J.P., Evans, P.G.H. & Schreiber, R.W. (Eds): *STATUS AND CONSERVATION OF THE WORLD'S SEABIRDS.* ICBP Technical Publication No.2: 271–291.

CUMPSTON, J.S. 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1). Antarctic Division, Department of External Affairs, Melbourne, Australia.

DEBENHAM, F. (Ed.), 1945: *THE VOYAGE OF CAPTAIN BELLINGHAUSEN TO THE ANTARCTIC SEAS, 1819–1821.* Transprinted by Hakluyt Society.

FALLA, R.A. 1937: Birds. *BANZARE Rep.*, Ser. B(2).

LUGG, D.J., JOHNSTONE, G.W. & GRIFFIN, B.J., 1978: The outlying islands of Macquarie Island. *Geogr. J.*, 144(2): 277–287.

MACKENZIE, D., 1968: The birds and seals of Bishop and Clerk Islets, Macquarie Island. *Emu*, 67: 241–245.

PRINCE, P.A., 1985: Population and energetic aspects of the relationship between blackbrowed and greyheaded albatrosses and the Southern Ocean marine environment. *In* Siegfried W.R., Condy, P.R. & Laws, R.M. (Eds): *ANTARCTIC NUTRIENT CYCLES AND FOOD WEBS.* Springer-Verlag.

PRINCE, P.A. & PAYNE, M.R., 1979: Current status of birds at South Georgia. *Bull. Brit. Antarct. Surv.*, 48: 103–118.

RAINE, T., 1824. Notice in regard to Macquarie Island. *Edin. Philos. J.*, XI: 46–50.

TICKELL, W.L.N., 1976: The distribution of black-browed and grey-headed albatrosses. *Emu*, 76: 64–68..

TICKELL, W.L.N. & PINDER, R., 1975: Breeding biology of the black-browed albatross *Diomedea melanophris* and grey-headed albatross *D. chrysostoma* at Bird Island, South Georgia. *Ibis*, 117(4): 433–451.

WEIMERSKIRCH, H., JOAVENTIN, P. & STAHL, J.C., 1986: Comparative ecology of six albatross species breeding on the Crozet Islands. *Ibis*, 128: 195–213.

(accepted 5 October 1987)

BANDING STUDIES OF GIANT PETRELS, *MACRONECTES* SPP., AT MACQUARIE ISLAND

by E.J. Woehler and G.W. Johnstone

(with five tables and seven text-figures)

WOEHLER, E.J. & JOHNSTONE, G.W., 1988 (viii): Banding studies of giant petrels, *Macronectes* spp., at Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 143–152. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Antarctic Division, Department of Science, Channel Highway, Kingston, Tasmania, Australia 7150.

Between 1 July 1967 and 3 June 1987, totals of giant petrels banded at Macquarie Island (54°30′S, 158°57′E) were northern giant petrel (*Macronectes halli*) — 3056 chicks, 583 adults; southern giant petrel (*Macronectes giganteus*) — 369 chicks, 47 adults.

Recoveries of known-age breeding birds of both species indicate age at first breeding to be six years. Birds banded as adults have been recovered breeding at ages of at least 24 years (northern) and at least 22 years (southern).

Recoveries, away from Macquarie Island, of northern giant petrels banded as chicks exhibit an eastward progression. Fifty-eight percent of recoveries were reported within 12 months of fledging and three birds were recovered in their ninth year.

Four giant petrels (2 northern, 1 southern and 1 unknown) banded elsewhere have been recovered at Macquarie Island.
Key Words: giant petrel, bird banding studies, Macquarie Island.

INTRODUCTION

The northern giant petrel (*Macronectes halli*) and the southern giant petrel (*Macronectes giganteus*) breed sympatrically on Macquarie Island (54°30′S, 158°57′E). The estimated breeding populations are approximately 1000 pairs of the northern giant petrel and 4000 pairs of the southern giant petrel (Johnstone 1977).

Prior to 1967, giant petrels were treated as a single, polymorphic species. However, Bourne & Warham (1966) recognised two species, based on differences in breeding behaviour and morphology. The northern giant petrel breeds on islands north of the Antarctic Convergence and at South Georgia (south of the Antarctic Convergence). The southern giant petrel breeds on islands from just north of the Antarctic Convergence south to the Antarctic Continent. A narrow zone of overlap exists and there are at least four localities (Marion Island, Iles Crozet, Macquarie Island and South Georgia) where the two species are sympatric (Johnstone 1977, Hunter 1984a).

Breeding biology of the southern giant petrel has been reported by Mougin (1968), Conroy (1972) and Hunter (1984a). Warham (1962) reported breeding data from Macquarie Island prior to the separation of the two species. Johnstone (1977) and Hunter (1985) described feeding ecology for both species.

Downes *et al.* (1954), Howard (1956), Ingham (1959) and Sladen *et al.* (1968) reported early banding and recovery data from giant petrels banded at Macquarie Island and South Georgia. Tickell & Scotland (1961) and Araya (1973) report more recent recovery data for southern giant petrels from Signy Island and Nelson Island respectively. Recovery data for known northern and southern giant petrels banded at South Georgia are reported by Hunter (1984b).

The aim of this paper is to report and analyse banding and recovery data for northern and southern giant petrels banded annually at Macquarie Island since the 1967–68 breeding season.

METHODS

Banding of adults and chicks has been undertaken in most seasons at Macquarie Island since the 1954–55 breeding season. From 1 July 1954 to 30 June 1967, a total of 7319 chicks and 810 adults, of unknown specific status, were banded. Unless specifically recognised at the time (or location) of recovery, these birds have been excluded from the analysis and subsequent discussion, as most recoveries refer to birds of unknown species. In the period 1 July 1967 to 30 June 1986, a total of 3056 chicks and 583 adult

TABLE 1

Banding of Giant Petrels at Macquarie Island, 1 July 1954 to 30 June 1986

Season	*Macronectes* spp.		*Macronectes halli*		*Macronectes giganteus*	
	chicks	adults	chicks	adults	chicks	adults
1954–55	272	200				
1955–56	1483	482				
1956–57	824	59				
1957–58	241	57				
1958–59	1525	2				
1959–60						
1960–61	2760*					
1961–62						
1962–63						
1963–64						
1964–65						
1965–66		1				
1966–67	214	9				
1967–68			128	498	4	3
1968–69			95			
1969–70			96		312	
1970–71			529*		26	
1971–72			101	1		1
1972–73			90			
1973–74			185			
1974–75			118	1		
1975–76			594*	42		43
1976–77			149	22		
1977–78			149	1		
1978–79			95*			
1979–80			129	10		
1980–81			119			
1981–82			73		1	
1982–83						
1983–84			116			
1984–85			158	8		
1985–86			132		26	
Total	7319	810	3056	583	369	47
Recoveries to 30 June 1986			73	5	5	1
%			2.39	0.86	1.36	2.13

* Seasons in which all chicks in the cohort were banded.

northern giant petrels and 369 chicks and 47 adult southern giant petrels were banded on Macquarie Island (table 1).

Three complete cohorts have been banded since 1 July 1967 (1970–71, 1975–76 and 1978–79) but in 1982–83 no banding was undertaken.

At Macquarie Island, northern giant petrels lay from late September to mid-October; eggs hatch at the end of November and the chicks fledge in mid-March. Chicks were banded on the nest between late December and February, in an area from Handspike Point to Aurora Point (fig. 1),

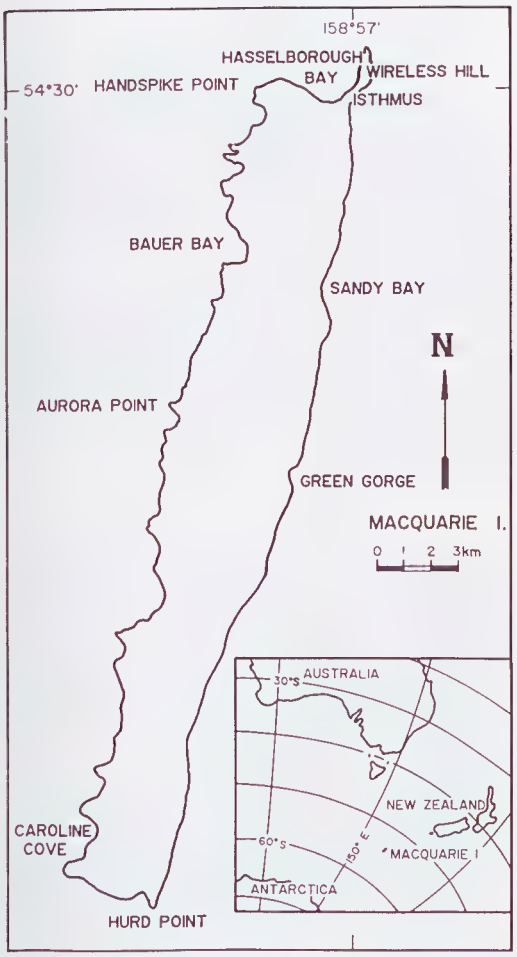

FIG. 1 — Locality map of Macquarie Island. Banding of chicks and searches for previously-banded adults are centred on the area between Handspike Point and Aurora Point.

concurrent with searches for banded adults. Adults were banded on the nest during the breeding season but, in some years, adults have also been banded during the winter months.

The breeding timetable for southern giant petrels is generally four to six weeks later than for northern; laying takes place in November, eggs hatch in mid-January and chicks fledge in May (Johnstone 1971, Warham 1962, Hunter 1984a, b). Chicks were banded on the nest in February and March in the same areas as northern giant petrels.

RESULTS

Breeding Recoveries of Northern Giant Petrels

A total of 63 adults (approximately 2.06% of those banded as chicks) has been recovered as known-age breeding birds. Two of these birds were found breeding in their sixth year. The oldest birds (n = 2) were in their 13th year (fig. 2A).

Minimum age of breeding (six years) was used to calculate the distribution of minimum ages

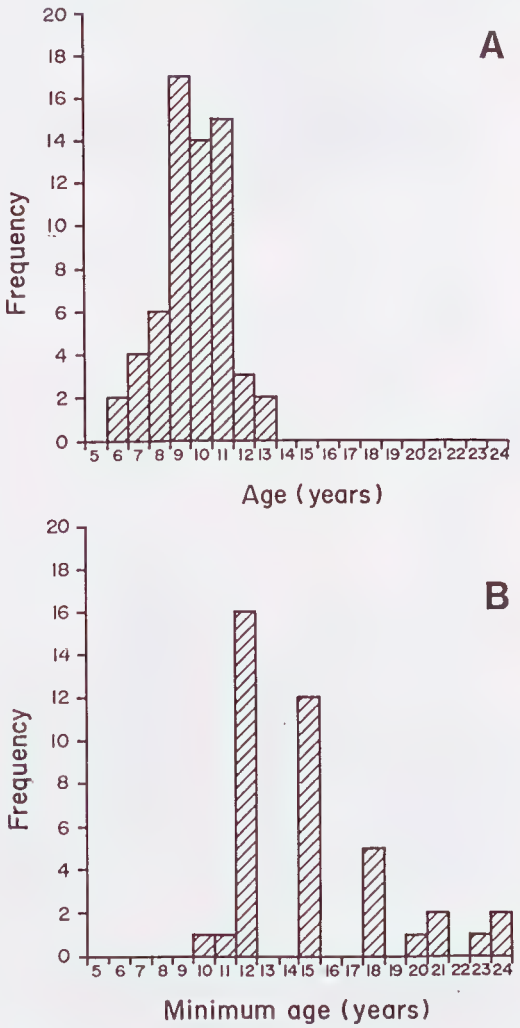

FIG. 2 — (A) Ages of breeding, known-age northern giant petrels at Macquarie Island, banded as chicks. (B) Minimum ages of breeding northern giant petrels at Macquarie Island, banded as "adult".

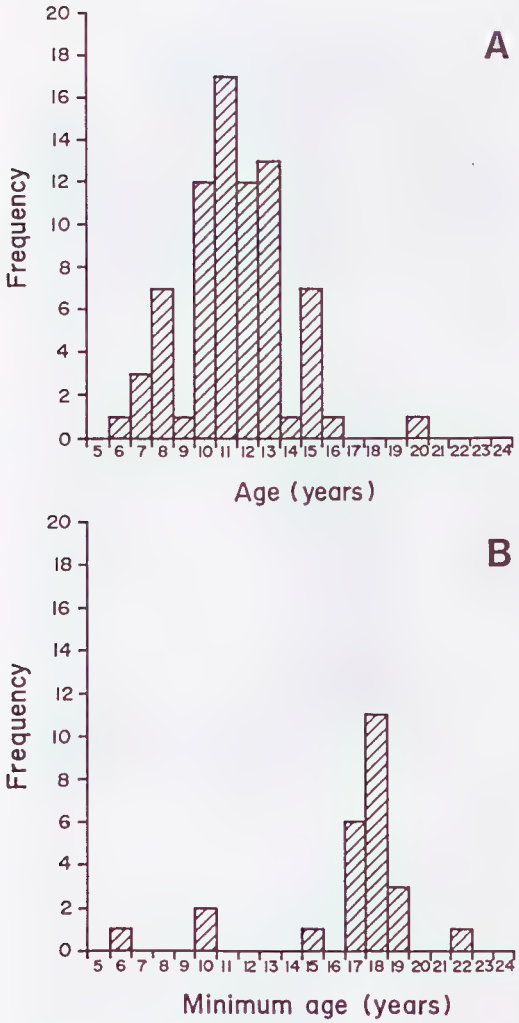

FIG. 3 — (A) Ages of breeding, known-age southern giant petrels at Macquarie Island, banded as chicks. (B) Minimum ages of breeding southern giant petrels at Macquarie Island, banded as "adult".

of birds banded as "adults" and recovered breeding in subsequent seasons (fig. 2B). Birds banded as breeding adults (October to February) were estimated to be aged "6+" (6 years or older) and adults banded during the autumn and winter months to be "3+", based on plumage. The oldest known northern giant petrel breeding recovery to date was aged 24+, at least 11 years older than any known-age breeding recovery at Macquarie Island (figs 2A & B).

Breeding Recoveries of Southern Giant Petrels

A total of 76 adults (approximately 20.6% of those banded as chicks) has been recovered as breeding birds of known-age. As with the northern giant petrels, the age of first breeding was six years. The oldest known-age breeding recovery was a bird aged 20 years, some seven years older than for the northern giant petrels (fig. 3A).

Using the same ageing protocols as above, the resultant distribution of the ages of 25 breeding adults banded as "adult" is given in figure 3B. The oldest known breeding recovery of a southern giant petrel from such birds was aged 22+, at least two years older than any known-age breeding recovery at Macquarie Island.

Distant Recovery Rates

The recovery locations of all northern and southern giant petrels banded at Macquarie Island as adults or chicks between 1 July 1967 and 30 June 1986 are shown in figures 4 and 5 respectively. Of the 3056 northern giant petrel chicks banded in this period, there have been 73 recoveries (2.39%) alive or dead away from Macquarie Island ("distant" recoveries). There have been five distant recoveries (0.86%) from the 583 adults banded.

Five of the 369 southern giant petrel chicks banded in the same period have also been recovered away from Macquarie Island and only one of the 47 adults banded has been recovered. These recovery rates are 1.36% and 2.13% respectively; they are similar to those reported by Sladen *et al.* (1968) and Hunter (1984b).

Age Structure of Distant Recoveries

One of the 73 distant recoveries of northern giant petrel chicks, which was made at the beginning of February, is considered too early (date of recovery is pre-fledging) and will be ignored in the analyses. Of the remaining 72 recoveries, 42 (58%) were reported in the 12 months following fledging. A further 14 (20%) were reported in the second year and 3 (4%) in the third, resulting in 82% of recoveries reported within the first three years after fledging. There were also three recoveries of nine-year-old birds banded as chicks (fig. 6A).

The distribution of recoveries in the first year after fledging ($n = 42$) is presented in figure 6B. The distribution does not differ significantly from the monthly mean of 3.5 ($\chi^2 = 19.2$, 11 d.f., $0.10 > p > 0.05$, NS).

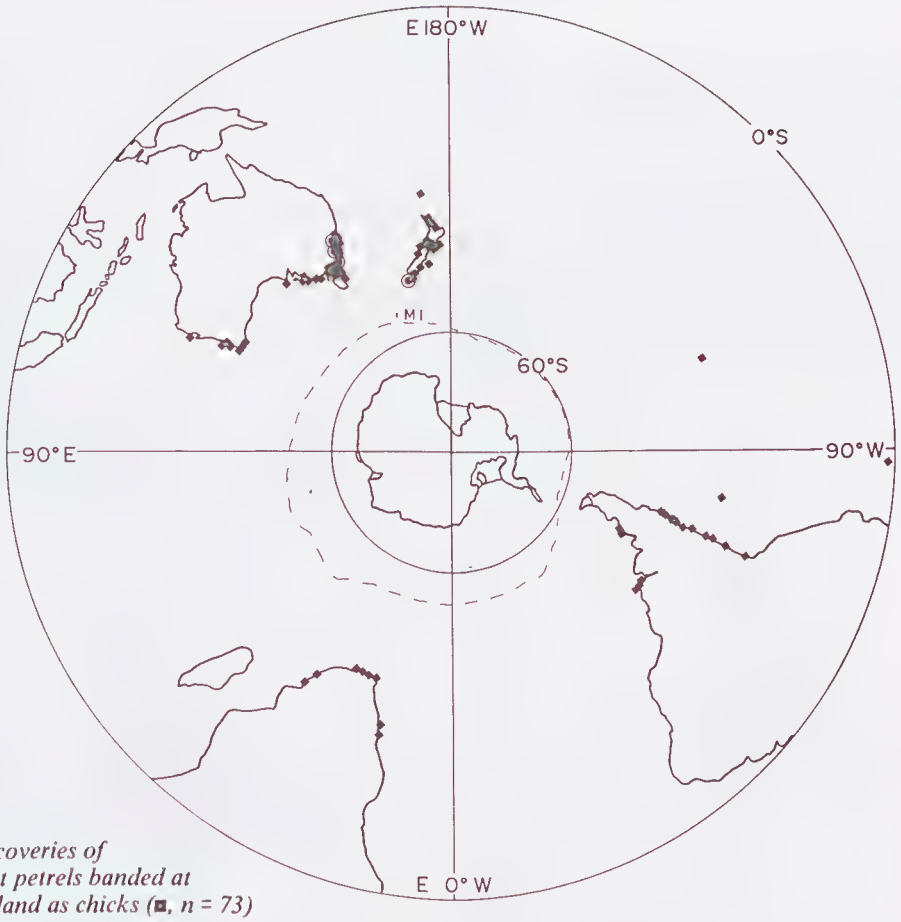

FIG. 4 — Recoveries of northern giant petrels banded at Macquarie Island as chicks (■, n = 73) and as adults (● , n = 5).

Locality of Distant Recoveries

The localities of all recoveries for both species banded at Macquarie Island are summarised in table 2. Details of the recoveries of northern giant petrels are given in the paragraphs following. There are insufficient recoveries of southern giant petrels (n = 6) for comparisons.

Examination of the latitudes of recoveries of northern giant petrels banded as chicks shows no recoveries north of the equator (Bourne 1967) nor any south of 50°S (fig. 7A). Recoveries between

TABLE 2

Summary of Localities and Approximate Distances where Recoveries of Northern and Southern Giant Petrels, Banded at Macquarie Island, have been Reported

Area	Northern giant petrel		Southern giant petrel		Approximate distance (km)
	chicks	adults	chicks	adults	
Australia	28	4	1	1	1200– 4000
New Zealand	17	1	1		1200– 2600
South America	19		2		10000–12500
Southern Africa	8				9000–11000
Pacific	1		1		6300– 7700
Totals	73	5	5	1	

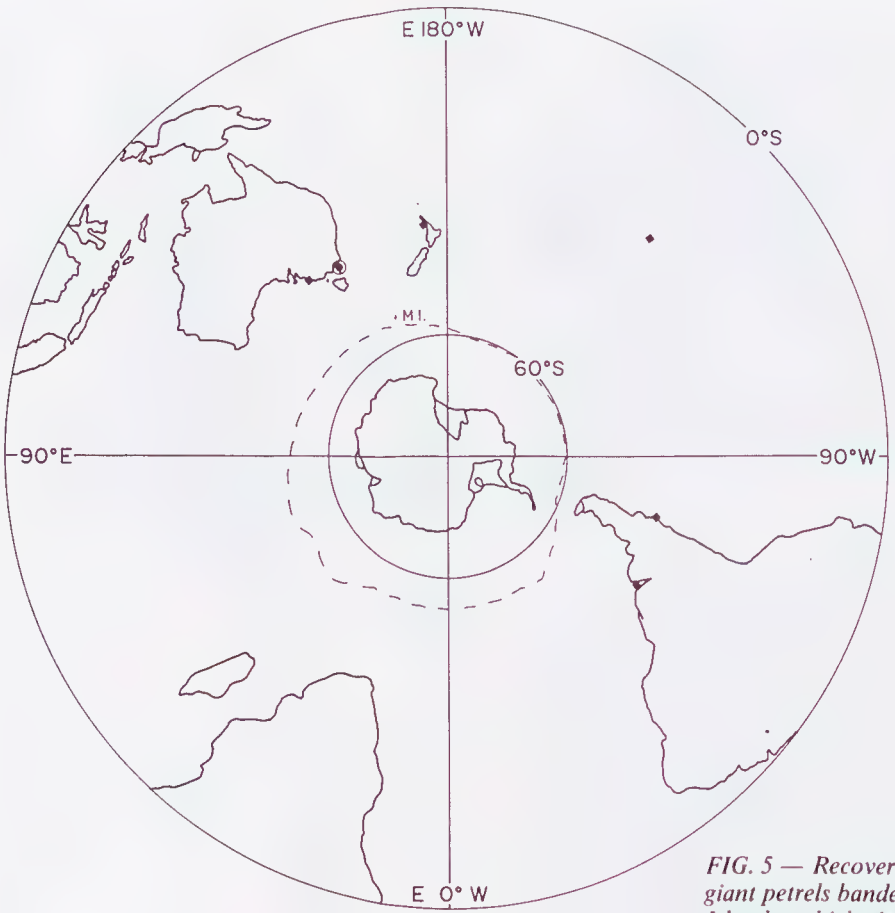

FIG. 5 — Recoveries of southern giant petrels banded at Macquarie Island as chicks (■, n = 73) and as adults (● , n = 5).

TABLE 3

Frequencies of Recoveries of Northern Giant Petrels Banded as Chicks at Macquarie Island

Latitude Range	Frequency		
	Year 1 n = 41	Other n = 30	Total n = 71*
00°00′S–04°59′S	1	0	1
05°00′S–09°59′S	0	0	0
10°00′S–14°59′S	0	0	0
15°00′S–19°59′S	1	0	1
20°00′S–24°59′S	2	1	3
25°00′S–29°59′S	5	3	8
30°00′S–34°59′S	16	5	21
35°00′S–39°59′S	10	14	24
40°00′S–44°59′S	5	6	11
45°00′S–49°59′S	1	1	2

* Two recoveries did not report latitude (see table 2)

TABLE 4

Median Month of Recoveries of Northern Giant Petrels Banded as Chicks and Recovered in First Twelve Months after Fledging (n = 42)

Area	n	%	Median month
New Zealand	9	21	March
South America	11	26	May
Southern Africa	4	10	June
Australia	18	43	July

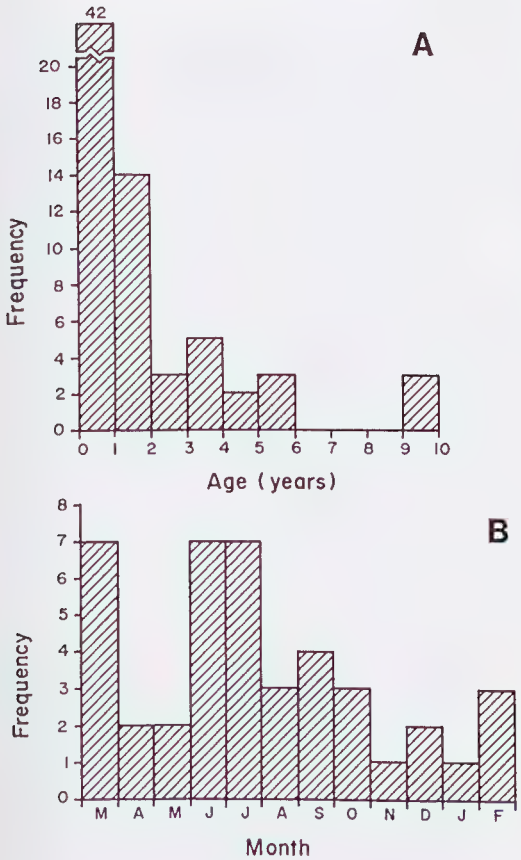

FIG. 6 — (A) Distribution of ages of distant recoveries of northern giant petrels banded at Macquarie Island, n = 72. (B) Distribution of recoveries within the first year after fledging of northern giant petrels banded at Macquarie Island, n = 42.

30°S and 40°S represent 63% of both the first year recoveries (n = 42 for first 12 months following fledging) and all recoveries (n = 72). Recoveries between 25°S and 45°S account for 88% of first year recoveries and 90% of all recoveries (table 3).

Similarly, an examination of the longitudes of recoveries (fig. 7B) shows that 62% of recoveries in the first year following fledging are between 90°E and 180°E (Australia and New Zealand). A further 26% are reported from South American longitudes and 11% from South Africa.

There was an eastward progression of recoveries of northern giant petrel chicks in the first 12 months following fledging (table 4). The median months of recoveries were March in New Zealand, May in South America, June in southern Africa and July in Australia.

Foreign-banded Birds Recovered at Macquarie Island

Details of four giant petrels banded at other localities and recovered at Macquarie Island are presented in table 5. The specific identity is known for three of the recoveries, the other is probably a southern giant petrel.

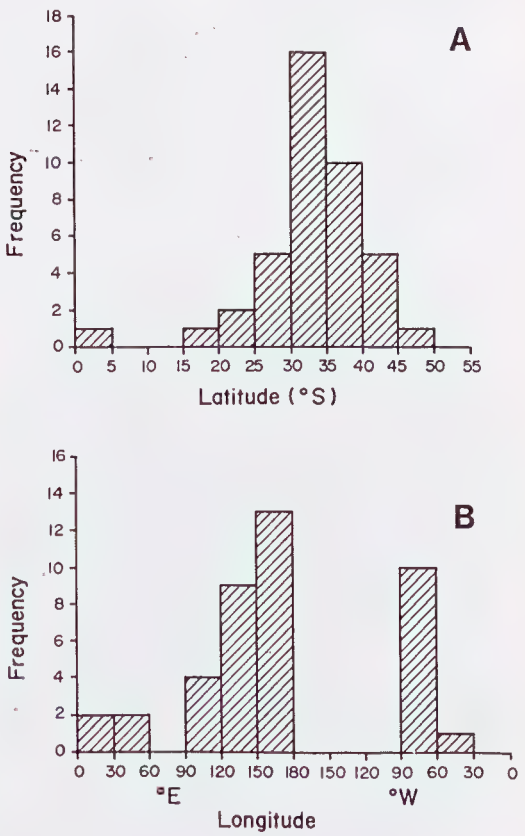

FIG. 7 — (A) Distribution of latitudes of distant recoveries of northern giant petrels banded at Macquarie Island, n = 41. (B) Distribution of longitudes of distant recoveries within the first year after fledging of northern giant petrels banded at Macquarie Island, n = 41.

TABLE 5

Foreign-Banded Giant Petrels Recovered at Macquarie Island

Species	Band No.	Banding Data	Recovery Date	Status
M. halli	140-20656	18 Jul 1970 Malabar, NSW, Aust. Age: "free-flying" (1+)	11 Sep 1981 Age: 12+	Breeding, on egg
M. halli	0-2728	18 Aug 1966 Campbell Is., NZ Age: breeding adult (6+)	5 Feb 1976 Age: 15+	Dead
M. giganteus	9-52005	22 Feb 1984 Marion Island Age: nestling	20 May 1984 Age: 1	Dead
	10156	(Argentinian Band) Location and age unknown	20 Jan 1986	Dead

DISCUSSION

Age at First Breeding and Longevity

The youngest known-age northern and southern giant petrels recovered breeding were six years old. These results agree with those reported by Hunter (1984a) at South Georgia. Conroy (1972) reported the age at first breeding of southern giant petrels at Signy Island to be five years, with evidence of sexual differences in age at first breeding, males breeding earlier than females. Similar evidence was presented by Mougin (1968).

Recoveries of breeding northern and southern giant petrels originally banded as "adults" indicate that individuals can live to at least 24 and 22 years respectively. These data suggest that individuals can contribute to the breeding population for at least 18 and 16 years.

Croxall (1981) reported mean life expectancies for breeding birds of 24.5 years for southern giant petrels but only 9.5 years for northern giant petrels. The results obtained in this study would indicate mean life expectancies for northern giant petrels to approach those of the southern giant petrel.

More detailed analyses of the age structure of the breeding populations are not possible, since search and banding efforts were not consistent from year to year.

Distant Recoveries

The distribution of distant recoveries for both species reported here (and in previous accounts) is strongly associated with the distribution of land masses in the Southern Hemisphere and the concomitant distribution of population centres. Such associations may introduce biases to recovery rates and the geographic distribution of reports of recoveries.

The eastward circum-polar progression of recoveries reported here is similar to those previously documented and can be attributed to fledglings using the predominant westerly winds (Downes *et al.* 1954, Tickell & Scotland 1961, Sladen *et al.* 1968, Hunter 1984b).

Hunter (1984b) reported a peak of southern giant petrel recoveries in July in the first year after fledging, but no such peak for northern giant petrels. The distribution of recoveries reported here (fig. 6B) shows small peaks in March, June and July, but these are not statistically significant.

High recovery rates in Australian waters reported in this study and others (Araya 1973, Hunter 1984b) suggest these waters may serve as wintering areas for both species. Wheeler (1973) and Jones (1973) reported the presence of large numbers of giant petrels in Victorian and New South Wales waters during winter months. Blakers *et al.* (1984) documented higher reporting rates

during winter months for both species in southern and southeastern Australian waters.

Serventy *et al.* (1971) and Johnstone (1974) suggested from observations at sea, that the Antarctic Convergence acted as an ecological barrier between the two species of giant petrels during the summer months but not in winter. The lack of any recoveries of northern giant petrels south of 50°S in this study supports such a conclusion. The few recoveries of southern giant petrels were also reported from north of an Antarctic Convergence; however, all but one were from winter months.

Only 4% (n = 3) of distant recoveries of northern giant petrels banded as chicks on Macquarie Island were made as birds of breeding age, i.e. birds six years of age or older. Of the 26 known-age recoveries of southern and northern giant petrels reported by Jones (1973), only one (3.9%) was a bird of breeding age (eight years old), all others were less than one year old. These data agree with published accounts (Tickell & Scotland 1961, Bourne & Warham 1966) that, with increasing age, birds are distributed close to the breeding areas. Warham (1962) reported adult giant petrels present at Macquarie Island throughout the winter months and Hunter (1984b) suggested that once birds had attained breeding age at South Georgia, they were unlikely to leave the island.

Foreign-banded Recoveries at Macquarie Island

Hunter (1984b) demonstrated that changes between natal and breeding sites were rare. The northern giant petrel, banded at Malabar, N.S.W., as a free-flyer and recovered breeding at Macquarie Island, had presumably also fledged at Macquarie Island. However, the other northern giant petrel, originally banded as a breeding adult at Campbell Island some 740 km to the northeast, may have changed its breeding location. One southern giant petrel (130-04218) banded at Macquarie Island in 1955 as a breeding adult was subsequently recovered breeding at Cape Crozier, Ross Island, Antarctica (E.J. Woehler & G.W. Johnstone, unpublished data). It would appear that changes in breeding locations occurs in both species.

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We wish to thank Mr H.R. Burton and Drs K.W. Lowe and P.G. Quilty for their help and encouragement. Mr M.A. Hindell provided advice and valuable discussions. The assistance of the Australian Bird and Bat Banding Schemes is gratefully acknowledged. Finally, we wish to thank the organisers of the Macquarie Island Symposium for the opportunity to present the results of this study.

REFERENCES

ARAYA, B., 1973: Recaptura de petreles gigantes anillados en Isla Nelson, Antarctica Chilena. *Revta Biol. Mar.*, 15: 111–114.

BLAKERS, M., DAVIES, S.J.J.F. & REILLY, P.N., 1984: *THE ATLAS OF AUSTRALIAN BIRDS*. Melbourne University Press, Melbourne.

BOURNE, W.R.P., 1967: Long-distance vagrancy in the petrels. *Ibis*, 109: 141–167.

BOURNE, W.R.P. & WARHAM, J., 1966: Geographical variation in the giant petrels of the genus *Macronectes*. *Ardea*, 54: 45–67.

CONROY, J.W.H., 1972: Ecological aspects of the biology of the giant petrel *Macronectes giganteus* (Gmelin) in the Maritime Antarctic. *Br. Antarc. Surv. Sci. Rep.*, No. 75: 1–74.

CROXALL, J.P., 1981: Aspects of the population demography of Antarctic and Subantarctic seabirds. *C.N.F.R.A.*, 51: 479–488.

DOWNES, M.C., GWYNN, A.M. & HOWARD, P.F., 1954: Banding of giant petrels at Heard and Macquarie Islands. *Emu*, 54: 257–262.

HOWARD, P.F., 1956: Banding of giant petrels at Heard and Macquarie Islands — II. *Emu*, 56: 401–404.

HUNTER, S., 1984a: Breeding biology and population dynamics of giant petrels *Macronectes* at South Georgia (Aves:Procellariiformes). *J. Zool. (Lond.)*, 203: 441–460.

HUNTER, S., 1984b: Movements of giant petrels Macronectes spp. ringed at South Georgia. *Ring. and Migr.*, 5: 105–112.

HUNTER, S., 1985: The role of giant petrels in the Southern Ocean ecosystem. *In* Siegfried, W.R., Condy, P.R. & Laws, R.M. (Eds): *ANTARCTIC NUTRIENT CYCLES AND FOOD WEBS*. Springer-Verlag, Berlin: 534–542.

INGHAM, S.E., 1959: Banding of giant petrels by the Australian National Antarctic Research Expeditions, 1955–1958. *Emu*, 59: 189–200.

JOHNSTONE, G.W., 1971: Bird in the hand — Giant petrels. *Aust. Bird Bander*, 9: 86–87.

JOHNSTONE, G.W., 1974: Field characters and behaviour at sea of giant petrels in relation to their oceanic distribution. *Emu*, 74: 209–218.

JOHNSTONE, G.W., 1977: Comparative feeding ecology of the giant petrels *Macronectes giganteus* (Gmelin) and *M. halli* (Matthews). *In* Llano, G.A. (Ed.): *ADAPTATIONS WITHIN ANTARCTIC ECOSYSTEMS*. Smithsonian Institute, Washington, D.C.: 647–668.

JONES, B., 1973: Studies of giant petrels at Malabar, New South Wales. *Aust. Bird Bander*, 11: 47–50.

MOUGIN, J.L., 1968: Etude ecologique de quatre especes de petrels antarctiques. *Oiseau*, 38: 1–52.

SERVENTY, D.L., SERVENTY, V. & WARHAM, J., 1971: *THE HANDBOOK OF AUSTRALIAN SEABIRDS*. A.H. & A.W. Reed.

SLADEN, W.J.L., WOOD, R.C. & MONAGHAN, E.P., 1968: The U.S.A.R.P. bird banding program, 1958–65. *In* Austin, O.L. Jnr (Ed.): *ANTARCTIC BIRD STUDIES*. Antarctic Research Series, Vol.12. American Geophysical Union, Washington, D.C.: 213–228.

TICKELL, W.L.N. & SCOTLAND, C.D., 1961: Recoveries of ringed giant petrels *Macronectes giganteus*. *Ibis*, 103a: 260–266.

WARHAM, J., 1962: The biology of the giant petrel *Macronectes giganteus*. *Auk*, 79: 139–160.

WHEELER, J.R., 1973: Giant petrel banding near Barwon Heads, Victoria. Aust. Bird Bander, 11: 11.

(accepted 14 October 1987)

SOUTHERN ELEPHANT SEALS AS SUBJECTS FOR PHYSIOLOGICAL RESEARCH

by M.M. Bryden

(with one text-figure and two plates)

BRYDEN, M.M., 1988 (viii): Southern elephant seals as subjects for physiological research. *Pap. Proc. Roy. Soc. Tasm.*, 122(1): 153–157, 2 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Formerly University of Queensland, now Department of Veterinary Anatomy, University of Sydney, New South Wales, Australia 2006.

Anatomical and physiological studies of southern elephant seals (*Mirounga leonina*), particularly in the post-natal period, raise questions of relative musculature growth, control of metabolism, circulation and temperature regulation, which could be important in our understanding of these processes in mammals and of their contribution to adaptation to environmental extremes.

Key words: elephant seals, marine mammals, Macquarie Island.

INTRODUCTION

Elephant seals, like other southern phocid seal species, are of great interest physiologically. As mammals that live protracted periods in the sea, they are subjected to certain physiological extremes not experienced by terrestrial mammals. For example, in diving for food, they experience rapid and great changes in pressure, and have developed means of breath-holding for long periods (in excess of one hour); similarly, in an environment in which heat loss from the body surface may be maximal, they must be able to control body temperature.

Since seals are amphibious, adaptation to the aquatic environment is different from that in totally aquatic species, such as whales. While making anatomical and physiological adaptations for life in the sea, seals must retain the ability to cope with living on land. The aim of this paper is to highlight a few of these special adaptations, using findings from the investigations of a research group over several years. Two major areas will be addressed, namely growth and development, and the regulation of body temperature. The paper is essentially a review and more details can be found in the references cited.

GROWTH OF BODY COMPONENTS

Elephant seals are born on land, and in certain respects they appear to be terrestrial mammals that develop their aquatic modifications postnatally. A body component vital for survival in cold water, but lacking at birth, is fat. In these seals, as in all other marine mammals, a large proportion of the body fat is deposited in the subcutaneous blubber layer which acts as essential insulation (Bryden 1964).

Lactation and Blubber

Lactation is brief in elephant seals (approximately three weeks) and growth is necessarily rapid, pups increase three- to four-fold on their birth weight in this period. Plates 1 and 2 illustrate the appearance of the pup at birth and at three weeks of age. Figure 1 shows that a large proportion of this body weight increase is blubber, but some growth of the musculature and other body systems occurs as well (Bryden 1969).

Muscles

Growth occurs at different relative rates among various muscle groups, favouring those important for terrestrial locomotion just after birth, and those important for swimming later (Bryden 1969). The pattern of development of the musculature is centripetal during the first weeks of postnatal life (the "terrestrial phase"). Growth spreads from the limbs and the head towards the body; the muscles surrounding the spinal column and those of the abdominal wall develop later in this phase of growth. However, these relative growth changes are reversed during the post-weaning fast, when the animal loses body weight significantly.

A considerable change in growth patterns occurs when the seals enter the sea and swim extensively (the "marine phase"). Then relative

PLATE 1
Day-old elephant seal pup and its mother. Note relative size of adult female and pup.

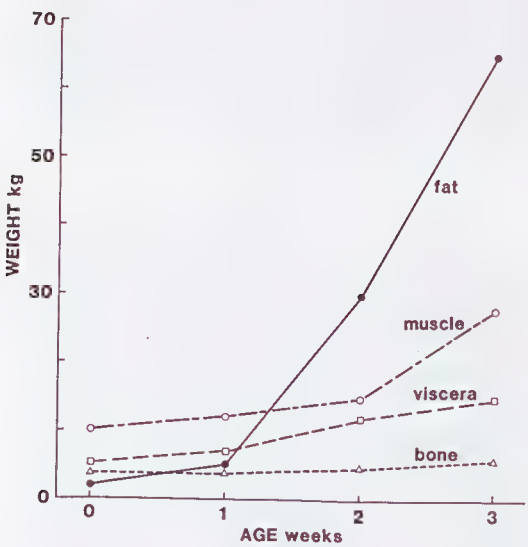

FIG. 1 — The increase in weight of four major body components of the elephant seal from birth to three weeks of age.

growth favours those muscle groups used extensively in aquatic locomotion, in particular the muscles surrounding the spinal column and the proximal muscles of the hind limb.

This evidence of alteration in the relative size of muscles, as a result of changes in the functional demands placed on them, has important implications in an area quite remote from seal biology — the study of methods used to improve meat production and quality.

Circulatory System

The development of the circulatory system reflects the change in the body's demand for oxygen when the seal first enters the sea and begins to dive (Bryden & Lim 1969); specifically, the amount of blood in the system increases from about 11% of body weight at birth to 16% in animals eight months old or older. Changes in blood volume, red cell count and haematocrit occur when the young seal goes to sea. Bryden and Lim estimated that the greater oxygen capacity of the blood would allow the animal to remain submerged 3.5 times longer than a terrestrial mammal, without recourse to other physiological adjustments.

PLATE 2
Twenty-one-day-old elephant seal pup and its mother. A younger pup is in the background.

REGULATION OF BODY TEMPERATURE

The First Hours of Postnatal Life

Elephant seals are born into what, for a mammal at least, is a hostile environment. They possess little physical insulation at birth; they are wet, from amniotic fluid, and may remain so for long periods, since rain, sleet or snow is common. Although temperatures are not extreme, they are frequently near freezing with, in addition, a significant wind-chill factor. Pups are afforded no protection by the mother and exhibit no behavioural characteristics that would aid retention of body heat, such as huddling against the mother, curling up to reduce body surface area, or seeking protection from wind and precipitation.

Although Laws (1953) stated that elephant seals may be partially ectothermic in the first days postpartum, this was not confirmed in recent investigations (G.J. Little, pers. comm.) which suggest strongly that pups are endothermic from the time of birth, and low body temperature is indicative of cold stress.

Vascular System

Newborn elephant seals possess the structures required for fine control of the microcirculation in the skin and used in the regulation of body temperature; the arrangement of the capillaries and, notably, the density and distribution of arteriovenous anastomoses are the same in newborn and adult seals (Molyneux & Bryden 1978).

The role of arteriovenous anastomoses in the peripheral circulation is, briefly, to permit arterial blood to be shunted directly into the venous system, bypassing the capillary bed (Molyneux & Bryden 1981). When the anastomoses are open, large volumes of blood are passed from arteries to superficial veins; thus the rate of perfusion of the skin by blood is increased considerably, resulting in greater heat loss from the skin surface.

As an indication of the importance of this mechanism in the control of body temperature, it

has been calculated that 1 ml of blood requires about 6 hours to flow through a normal capillary (diameter 10 μm), while an arteriovenous anastomosis with diameter 100 μm would pass the same volume of blood in about 2 seconds.

Thus, dermal arteriovenous anastomoses function to *increase* heat loss from the skin surface when they are open; heat *conservation* requires a reduction of blood flow to peripheral structures in a cold environment, which may be achieved to some extent by constriction of the major arteries. This is known to occur during the diving response (Elsner 1969), and may be aided by large arteriovenous shunts observed in the more proximal parts of the limbs (G.S. Molyneux and M.M. Bryden, unpublished observations), which would permit passage of blood directly from larger arteries to veins, thus bypassing the peripheral vascular bed.

Newborn pups appear to be endothermic, and arteriovenous anastomoses are probably functional at birth, although direct measurements have not been made. However, control of peripheral blood flow is insufficient to explain how the pup survives the first few hours or days following birth. The skin temperature is relatively high in pups soon after birth, and heat loss must be significant. Indeed, Laws (1953) recorded many deaths of pups early in the breeding season at South Georgia, when deep snow covers the tussock areas. The pup's warm skin melts the snow and a deep hole develops, into which the pup sinks and becomes trapped.

Because of the relative lack of physical insulation, mechanisms are required to produce sufficient body heat to balance what is probably a large heat loss from the body surface at birth. The most obvious mechanism is shivering, but this has been observed only rarely in elephant seal pups, either in very small pups or in those with little physical insulation that have been trapped by waves and spent considerable lengths of time in the sea. Another mechanism would be the activation of large deposits of brown adipose tissue. This tissue, present in newborn young of a number of species, including human, has a high metabolic rate and has the capacity to produce large amounts of metabolic heat rapidly (Smith & Horwitz 1969). However, examination has failed to reveal any such tissue in the newborn Weddell seal (Elsner *et al.* 1977) or elephant seal (G.J. Little, pers. comm.).

Pineal Gland

The pineal gland, a small structure attached to the brain, serves as an intermediary between the external and internal environment of mammals. It is particularly sensitive to light, mediated through the optic system, but it may be influenced by other factors as well.

Recent studies on elephant seals at Macquarie Island, and on Weddell seals in Antarctica, have shown that the pineal gland is very large and very active at birth (Bryden *et al.* 1986).

In the circulating blood, the concentration of the hormone melatonin, produced by the pineal, can be measured by radioimmunoassay, and thereby serves as an indicator of pineal activity. Judged by the concentration of melatonin in the blood, the activity of the pineal gland is greatest during the first one or two days after birth. After the lactation period, the size of the pineal declines in a few weeks, suggesting that this gland has a specific role to play in early postnatal life. Several pieces of circumstantial evidence led us to suggest that this role is thermoregulation, but we can only guess at the physiological mechanisms involved at this stage. Further work is required, and the elephant seal is a valuable species in the study of the pineal gland, the physiological significance of which is not yet understood fully.

Endocrine Control of Metabolism

Present investigations by G.J. Little, a Ph.D. student who spent a year at Macquarie Island in 1985, are aimed at gaining an appreciation of the level of activity of a number of endocrine glands during the early postnatal period in elephant seals. He is examining, anatomically and physiologically, the thyroid and adrenal, to determine their possible roles in maintaining body temperature during the first hours and days of postnatal life.

CONCLUSIONS

Anatomical and physiological investigations of elephant seals at Macquarie Island over several years have made an important contribution to our understanding of aspects of relative growth in mammals.

Recent investigations and some in progress, as well as others being planned, may contribute to understanding the mechanisms involved in adaptation to environmental extremes.

REFERENCES

BRYDEN, M.M., 1964: Insulating capacity of the subcutaneous fat of the southern elephant seal. *Nature*, 203: 1299–1300.

BRYDEN, M.M., 1969: Relative growth of the major body components of the southern elephant seal, *Mirounga leonina* (L.) *Aust. J. Zool.*, 17: 153–177.

BRYDEN, M.M., GRIFFITHS, D.J., KENNAWAY, D.J. & LEDINGHAM, J., 1986: The pineal gland is very large and active in newborn antarctic seals. *Experientia*, 42: 564–566.

BRYDEN, M.M. & LIM, G.H.K., 1969: Blood parameters of the southern elephant seal (*Mirounga leonina* Linn.) in relation to diving. *Comp. Biochem. Physiol.*, 28: 139–148.

ELSNER, R., 1969: Cardiovascular adjustment to diving. *In* Anderson, H.J. (Ed.): *THE BIOLOGY OF MARINE MAMMALS*. Academic Press, London: 117–145.

ELSNER, R., HAMMOND, D.D., DENISON, D.M. & WYBURN, R.S., 1977: Temperature regulation in the newborn Weddell seal, *Leptonichotes weddelli*. *In* Llano, G.A. (Ed.): *ADAPTATIONS WITHIN ANTARCTIC ECOSYSTEMS*. Smithsonian Institution, Washington, DC: 531–540.

LAWS, R.M., 1953: The elephant seal (*Mirounga leonina* Linn.) I. Growth and age. *Falkland Islands Dep. Surv., Sci. Rep.* No.8.

MOLYNEUX, G.S. & BRYDEN, M.M., 1978: Arteriovenous anastomoses in the skin of seals. I. The Weddell seal *Leptonychotes weddelli* and the elephant seal *Mirounga Leonina* (Pinnipedia: Phocidae). *Anat. Rec.*, 191: 239–252.

MOLYNEUX, G.S. & BRYDEN, M.M., 1981: Comparative aspects of arteriovenous anastomoses. *In* Harrison, R.J. & Holmes, R.L. (Eds): *PROGRESS IN ANATOMY*. Vol.1. Cambridge University Press, UK: 207–237.

SMITH, R.E. & HORWITZ, B.A., 1969: Brown fat and thermogenesis. *Physiol. Rev.*, 49: 330.

(accepted 30 November 1987)

THE HISTORY OF THE ELEPHANT SEAL INDUSTRY AT MACQUARIE ISLAND AND AN ESTIMATE OF THE PRE-SEALING NUMBERS

by Mark A. Hindell and Harry R. Burton

(with two tables and four text-figures)

HINDELL, M.A. & BURTON, H.R., 1988 (viii): The history of the elephant seal industry at Macquarie Island and an estimate of the pre-sealing numbers. *Pap. Proc. R. Soc. Tasm.*, 122(1): 159–176. Paper presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Antarctic Division, Department of Science, Channel Highway, Kingston, Tasmania, Australia 7150.

A comprehensive list was compiled of all sealing ships that visited Macquarie Island (54°30'S, 158°57'E) between 1810 and 1919 and, where possible, their cargoes. Approximately 207 sealing visits were made to Macquarie Island in 109 years and an estimated 8380 tuns of elephant seal oil removed. The major sealing effort seems to have been in the first 20 years, between 1810 and 1829, when almost half of the voyages occurred and over half of the oil was collected. For the present study, a mathematical model was devised to examine the responses of the population to the estimated annual harvest of seals from 1810–29. Given the often incomplete nature of the sealing records, accurate estimates of the pre-sealing elephant seal population were impossible to obtain, but the model suggests that it may have been in the region of 93 000 to 110 000 animals. The major impact of sealing activity was between 1820 and 1830, when the population was reduced by approximately 70%. Numbers are thought to have recovered to near pre-sealing levels by the 1900's, when the level of sealing was within the sustainable yield of the population.

Key Words: elephant seal, sealing industry, sealing ships, Macquarie Island.

INTRODUCTION

Southern elephant seals (*Mirounga leonina*) have large deposits of blubber: a large male can have over 300 kg of blubber and females approximately 100 kg (Winter & Nunn 1950, Bryden & Stokes 1969, Gales & Burton 1987). The blubber plays an important role in thermoregulation and energy storage (Bryden 1968). The blubber also has a very high proportion (around 84%, Hamilton 1949) of oil of a particularly high quality, which had important industrial and commercial applications in the eighteenth, nineteenth and early twentieth centuries (Hamilton 1839, Scammon 1874).

The combination of large blubber deposits, high yield of quality oil and the relative ease of procuring and extracting it meant that the southern elephant seal was subjected to intense commercial harvesting at all its major breeding sites in the last century. The exploitation was so intense in some areas, such as in the islands of Bass Strait in southeastern Australia, that the species was completely exterminated. Macquarie Island (54°30'S, 158°57'E) is one of the major breeding sites of the elephant seal, and has approximately one-sixth of the world population of 600 000 breeding there (McCann 1985). The population was exploited from the time of its discovery by sealers in 1810 until 1919 (Cumpston 1968). The extent of these activities and their impact on the population have not been documented, although generally assumed to have been severe (Carrick & Ingham 1962a, Ling & Bryden 1982).

This paper attempts to assess the extent and impact of the seal oil industry on the elephant seal population of Macquarie Island. Old sealing and shipping records were used to estimate the number of seals killed annually during the whole period of exploitation and a population model was devised to estimate the initial size of the Macquarie Island elephant seal population and to examine the responses of the population to the estimated levels of harvesting.

METHODS

Visits of Sealing Ships to Macquarie Island

A comprehensive list was compiled of all ships that visited Macquarie Island between 1810 and 1930, giving (a) the date and port of departure, (b) the date of arrival and departure at Macquarie Island, and (c) the date and port of return (Appendix 1). Cumpston (1968) was the principal source of information, although the details were

checked and expanded through lists of shipping arrivals and departures from Sydney and Hobart (Cumpston 1963, Nicholsen 1963, 1983, 1985). The cargoes of the ships were also recorded where possible, but much of this information was incomplete.

Amount of Oil Removed

The amount of oil removed in the unknown cargoes was assumed to equal the average oil tunnage of the known cargoes in that year; the cargoes were usually listed in tuns, gallons, barrels or casks. All of the results presented here are expressed as tuns; the following conversions (Rhys Richards, pers. comm.) were used where necessary: 1 tun = 252 gallons (Kemp 1976) or 2.3 casks or 8 barrels (1 barrel = 31.5 gallons).

Not all of the oil collected left the island. Small amounts were used by the sealers for lighting and heating, and it was not uncommon for some to be lost during the hazardous loading procedures (Cumpston 1968). We have assumed an annual loss of 5%, based largely on the few records of rafting losses in Cumpston (1968). Some ships also visited Campbell Island on the same voyage, but only 48 tuns of oil are known to have come from this source (Kerr 1976). It is also possible that some fur seal carcasses were rendered down for oil during the first few years of exploitation.

Oil Yield Per Seal

Several assumptions were needed to estimate how many elephant seals were killed to produce the oil tunnage collected at Macquarie Island. There are no records of the relative number of male and female seals taken. These are critical data, in view of the large size difference between males and females, and the very different effect on population replacement of harvesting males as opposed to females (see below).

Data on oil yield per seal have been reported anecdotally. Cumpston (1968) reported that bulls newly ashore at Macquarie Island yielded 0.5 tuns of oil, but this decreased to 0.33 tuns as the breeding season progressed. Females produced only 0.1 tuns. Busch (1985) estimated that 8.3 cows were needed to make up one tun of oil, or approximately 0.12 tuns of oil per seal, and he used this figure as a basis for calculating total elephant seal harvests around the world.

The most reliable information on oil yield comes from South Georgia, where there was an elephant seal industry operating periodically from the late 1700's through to 1964 (McCann 1980). The industry became regulated in 1910 and records were kept subsequently of the number of seals killed and the annual oil harvest (Laws 1960). The average yield per seal increased from 1.15 to 2.01 barrels of oil per seal between 1910 and 1955, as the sealers improved their processing techniques (Laws 1960). Consequently, only the first ten years (i.e. 1910–20) of data from South Georgia were used, as the level of technology of blubber extraction at that time is likely to be similar to that used at Macquarie Island. These data were averaged to give 4.98 seals per tun of oil, or 0.2 tuns per seal. This represents approximately 180 kg of oil per seal, assuming a density of blubber of 0.95 gml^{-1} (Gales & Burton 1987), and 210 kg of blubber, assuming an 84% oil content in the blubber (Hamilton 1949). This agrees quite well with the mean blubber weight of 220 kg calculated from ten males at Heard Island (Gales & Burton 1987). This figure was used as the average yield per male, assuming that the Macquarie Island sealers used similar techniques and that the seals were of similar sizes. Female elephant seals were assumed to yield one-third of this, or 0.07 tuns of oil (70 kg of blubber) per seal. It was further assumed that oil yield per seal did not change during the hundred-odd years of exploitation at Macquarie Island. In reality, it is likely that oil yield improved with the introduction of the coal-fired, high-pressure digesters in the last 30 or 40 years (Cumpston 1968).

Population Model

A model of an elephant seal population was devised to help estimate the initial size of the population prior to sealing. Population models have been used many times to describe other marine mammal populations and to assess the potential impact of exploitation (e.g. Allen & Kirkwood 1978, Beddington & Kirkwood 1980, Shaughnessy & Best 1982). The most fundamental parameters that must be incorporated into any models are sex ratio at birth, longevity of each sex, survivorship and mortality of each age class, age at first breeding, pregnancy rate and population size. In the following model, all parameters except the pregnancy rate are density independent, that is, are not directly affected by the size of the population.

Data from Macquarie Island were used whenever possible, but when these were unavailable, data were taken from the population at South Georgia. The parameters selected were as follows:

(1) A sex ratio at birth of 54 males to 46 females was derived from Carrick *et al.* (1962) for the Macquarie Island population in the 1950's.

(2) The age-specific natural mortalities rate adopted was calculated by McCann (1985) for the population at South Georgia. We have not allowed for possible density-dependent effects on pup mortality. Although it has been reported that pup mortality increases in crowded harems (Carrick & Ingham 1962b) there is no quantitative information to use as a basis in our model. Consequently, our model may tend to overestimate pup survivorship in large populations.
(3) Age at first parturition was taken to be four years (Carrick *et al.* 1962).
(4) Breeding age for males was assumed to be eight years. Males in an unexploited population usually do not take an active part in breeding until they are at least ten years old (Carrick *et al.* 1962, Jones 1981), although they are physiologically capable at a much earlier age (Griffiths 1984). We have assumed that all males over eight years old are potential breeders that can replace older males removed by the sealers.
(5) An initial pregnancy rate was taken as 88% in a stable population (McCann 1985).
(6) A sex ratio among breeding adults of one male to twelve females (Carrick *et al.* 1962, Hindell & Burton 1987) was used. It was assumed that the pregnancy rate of 88% would be achieved while this sex ratio was maintained. Once the surplus males were removed from the population and the number of active breeding males decreased, the pregnancy rate was also assumed to decrease, as there were now fewer males to mate with the females. The pregnancy rate was assumed to decrease linearly with the decrease in the number of males, once the surplus had been removed.

The model also assumed that the animals removed from the population by sealers were all of breeding age; it is possible that the sealers took juvenile seals, during their moulting haul-out in November and December, but for most other times of the year only adult animals are ashore. It is known that, during 1890–1919, the sealers changed their attentions from elephant seals to penguins with the end of the breeding season in November (Cumpston 1968). Other assumptions of the model were that the sealers took males first, only taking females when all of the accessible males were removed, that all the animals of breeding age and above were available to the sealers, and that the population was initially stable.

The number of animals in each age class for each sex was then calculated for a series of population sizes. The total number of breeding males and females and the number of surplus males which could be harvested without affecting that population was then calculated. For example, a population of 79 369 seals would have 21 000 females and 4401 males of breeding age and above. Of these 21 000/12 = 1750 males would be needed for breeding and 2651 males could be killed without affecting pup production.

The amount of oil collected in the first year of sealing was then introduced into the model, initially assuming that this consisted entirely of males. The model then faced a series of options:

(1) If the amount of oil taken represented fewer males than the surplus, the number of males taken was deducted from the total number of breeding males, and the next year's population structure calculated.
(2) If the amount of oil taken represented more than the surplus, but fewer than the total number of breeding males, then the number of males taken was deducted from the total number of breeding males and the new adult sex ratio calculated. Taking account of the reduced number of males, a new pregnancy rate and the next year's population structure were calculated.
(3) If the amount of oil collected represented more than the total number of breeding males, it was assumed that all of the males available that year were taken and that the remainder of the oil was made up from females. In these years, the pregnancy rate was assumed to be zero as no males were left to impregnate the females. The next year's population structure was then calculated.
(4) If the amount of oil collected was more than was represented by all of the breeding males plus all of the breeding females available in that year, this was taken as preemptive evidence that the initial population size was too small. The process was then repeated with a larger initial population size.

By using the model in this way, it was possible to estimate the minimum initial population that could have sustained the observed level of sealing between 1810 and 1829.

RESULTS

Sealing Activity Between 1810 and 1916

There were six distinct phases in the exploitation of elephant seals at Macquarie Island (table 1):

(1) the pre-sealing phase prior to 1810;
(2) the first sealing phase between 1810 and 1829, when 97 ships, or an average of five ships per year, visited the island;
(3) a "lapse" phase of 44 years between 1830 and 1874, during which only three sealing ships called

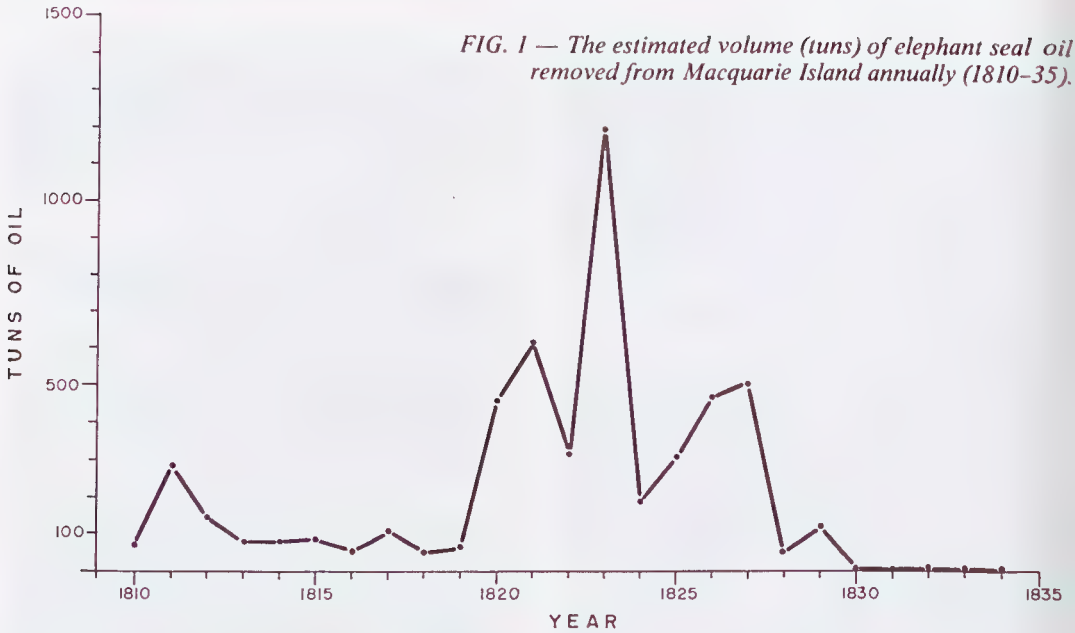

FIG. 1 — The estimated volume (tuns) of elephant seal oil removed from Macquarie Island annually (1810–35).

at the island, two in 1834 and one in 1851; several non-sealing ships visited the island during this time;

(4) the resumption of sealing activity between 1875 and 1889, when 30 ships visited the island (an average of two ships per year);

(5) the "Hatch" years between 1890 and 1919, when Joseph Hatch had the exclusive rights to work Macquarie Island; 75 sealing voyages were made to the island during this time, an average of almost three ships per year;

(6) the recovery phase from 1919, when sealing stopped at Macquarie Island, to the present day, during which time the population has been commercially unexploited.

Amount of Oil Collected

A total of 4400 tuns of oil are known to have left the island between 1810 and 1829 on 81 ships (table 1). Sixteen vessels, or 16.5% of the ships visiting the island, left with unlisted cargoes. The total volume of oil estimated to have been collected during this time, with a 5% addition for the estimated ship loading loss, was 5533 tuns. The amount of oil removed per year varied considerably during this time (fig. 1). For the first decade, relatively small amounts of oil were removed; usually less than 150 tuns. Sealing activity increased significantly in 1820 and reached a peak yield of nearly 1200 tuns in 1823, before it dropped away

TABLE 1

The six phases in the history of elephant seal exploitation at Macquarie Island

Phase	Years	Sealing Voyages			Oil Removed (tuns)*		
		Listed Cargoes	Unlisted Cargoes	Total	Listed Cargoes	Est. unlisted Cargoes	Total (+5%)**
1	?–1810	0	0	0	0	0	0
2	1810–1829	81	16	97	4400	869	5533
3	1830–1874	3	0	3	30	0	30
4	1875–1889	26	6	32	557	129	720
5	1890–1919	52	23	75	800	1200	2100
6	1920–1985	0	0	0		0	0

* Divided into known amount removed in the listed cargoes and the amount estimated to have been removed in the unlisted cargoes.

** Total estimated volume removed, including a 5% correction for loss on the island.

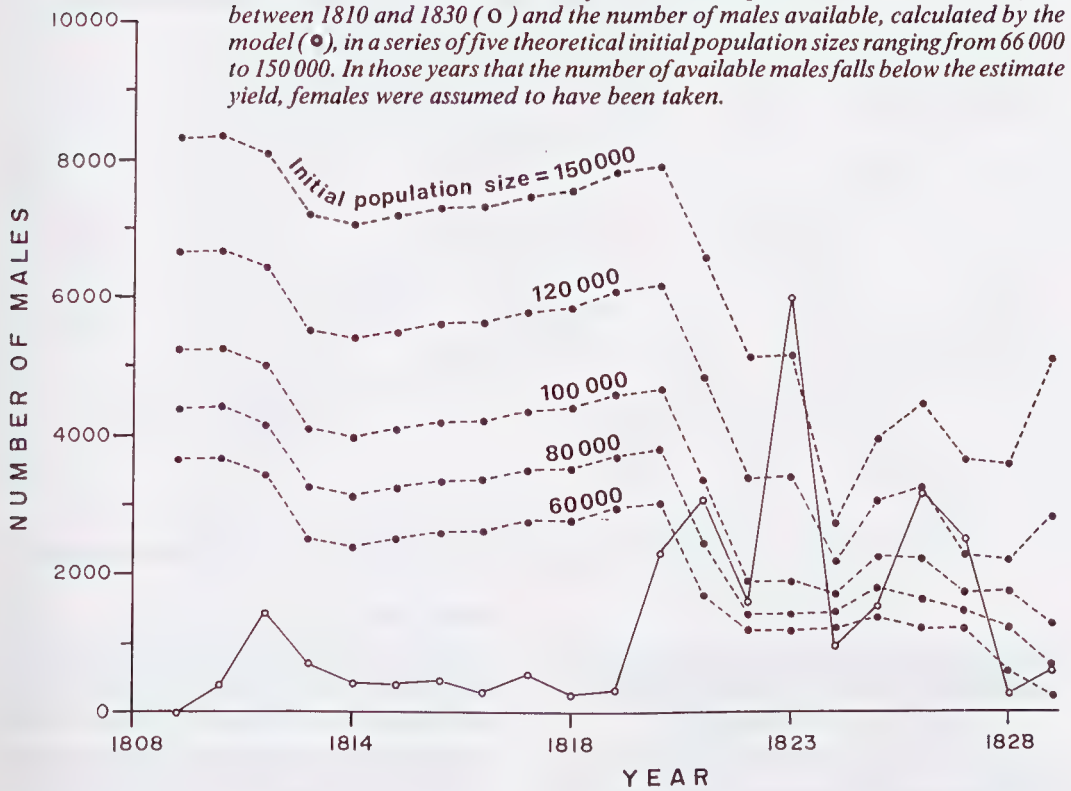

FIG. 2 — The estimated number of adult male elephant seals removed each year between 1810 and 1830 (O) and the number of males available, calculated by the model (⊙), in a series of five theoretical initial population sizes ranging from 66 000 to 150 000. In those years that the number of available males falls below the estimate yield, females were assumed to have been taken.

over the next seven years. During the lapse phase (1830–74), one tun of oil was collected from two visits in 1834 and 147 seals (yield approximately 129 tuns of oil) were reported to have been killed in 1851, when only one call by a sealing ship is recorded. Sealing resumed in 1875, and 557 tuns of oil are known to have been removed in 26 voyages between then and 1889. There were six ships (20% of the voyages) with unlisted cargoes at this time. The total estimated volume of oil collected was 720 tuns.

The records of the amount of elephant seal oil removed from Macquarie Harbour are less complete from 1890. Gangs of sealers were usually deployed before the elephant seal breeding season, around August, and they would work the seals until most of the adult seals had left in mid- to late November. They then switched to taking penguins for the next two to three months until they too left the island in March. Often the two types of oil were not distinguishable in the cargo manifests. Approximately 3700 tuns of oil were removed from the island between 1890 and 1916, of which 700 tuns are known to have been penguin oil and 800 tuns elephant seal oil. Assuming the remaining 2200 tuns of oil were composed of similar proportions of penguin to elephant seal oil, approximately 2000 tuns of elephant seal oil (or 2100 allowing for a 5% annual loss rate) were collected between 1890 and 1916.

Oil Yield Per Voyage

The variability in oil collection in different years could be due to differences in sealing effort. It was difficult to assess sealing effort directly, therefore the amount of oil removed per voyage was used as an index of return per unit of sealing effort (fig. 2). The number of tuns removed per ship fluctuated between 1810 and 1819, but in 1820 it increased dramatically. From 1821 the amount of oil returned per sealing voyage decreased steadily from 117 tuns to 26 tuns in 1828. Such a drop in return per unit effort for the sealers during this time would strongly suggest that the available resources were rapidly being depleted. Cumpston (1968) gives several anecdotal examples of how the sealers were finding it difficult to find seals in these later years.

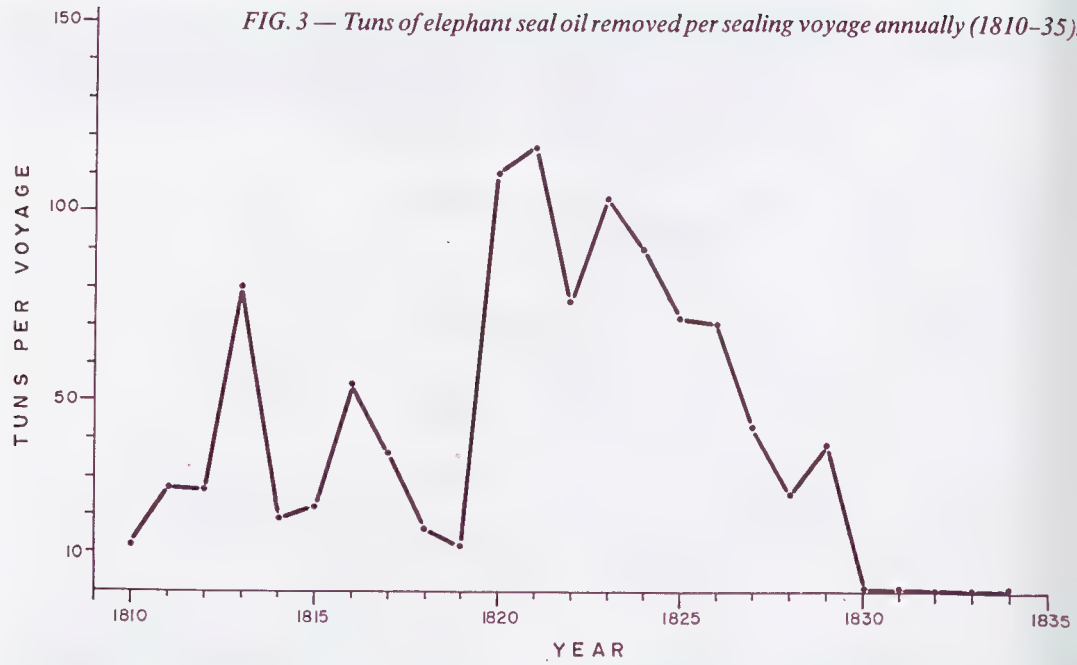

FIG. 3 — Tuns of elephant seal oil removed per sealing voyage annually (1810–35).

Initial Population Size and the Impact of Sealing Between 1810 and 1829

The model identified an initial population size of 66 100 as the smallest population that could have supported the estimated sealing level. This population size would have required that all of the males available were taken each year from 1821 on (fig. 3). In those years considerable numbers of females would also have had to be taken to produce the estimated oil yields.

An initial population of 80 000 would produce an abundant number of males (3000–4500), far in excess of what was taken for the first 13 years, but in the decade of heavy sealing pressure, the number of males available was greater than or equal to the number taken in five years. Females would need to have been taken in the remaining five years of this period to account for the observed amount of oil removed.

Initial populations of 100 000 or 120 000 would have been little affected by the first 12 years of relative low sealing pressure, and during the intense hunting the number of males taken exceeded the number available in only three years, with females needing to be taken in those years. If the original population was 150 000, the number of males available would have exceeded the number taken in all but one year.

The steady decline in the tuns of oil removed from the island per voyage in the nine years from 1821–1830 (fig. 2) suggests that it was becoming progressively more difficult to find seals. Given this, the relative abundances of males produced by the theoretical population size of 150 000 seem to rule out populations of this or greater sizes originally existing on the island. A pre-sealing population of between 80 000 and 120 000 would seem to best fit the observed sealing pressure and the consequent decline in sealing returns.

A population from the middle of this range (100 000) would have declined to a low of 26 183 in 1827; an overall decline of 67%, with a total of 21 979 males and 15 648 females taken (table 2).

This interpretation has assumed that all of the seals on the island were exploited by the sealers, but there is some evidence to suggest that this might not be the case. The sealers seem to have concentrated their activities in the areas of highest population numbers and there are no written records of any activity on the west coast between Bauer Bay and Caroline Cove (Cumpston 1968). This stretch of coast is particularly exposed and rugged, offering no anchorage to ships, so any oil collected here would have been very difficult to remove. Also, there were probably relatively few seals there. In 1985, only 15.8% of the island's seals were located along this piece of coast (Hindell & Burton 1987). Consequently, the estimates of initial population size are probably underestimates. When

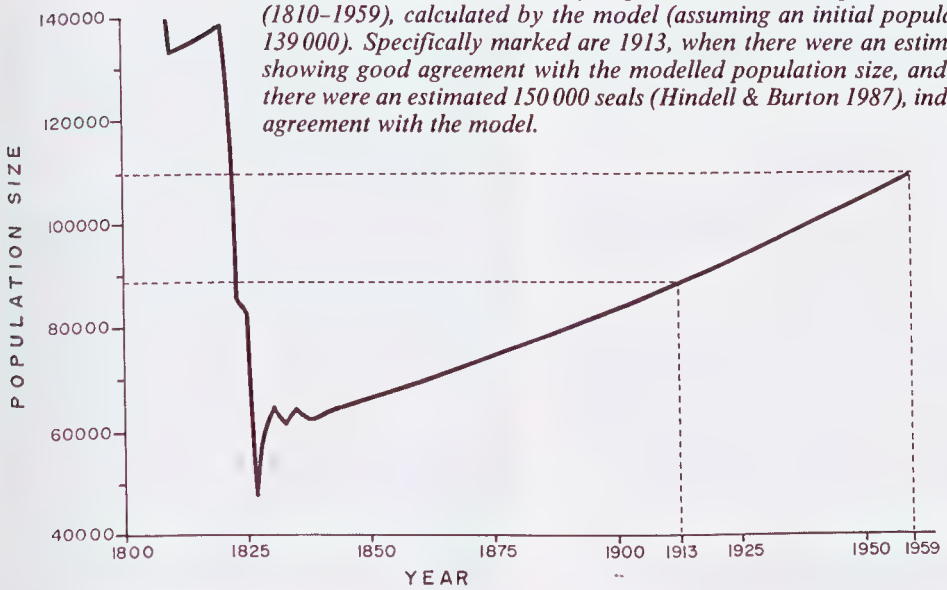

FIG. 4 — The total number of elephant seals on Macquarie Island annually (1810–1959), calculated by the model (assuming an initial population size of 139 000). Specifically marked are 1913, when there were an estimated 88 000, showing good agreement with the modelled population size, and 1959, when there were an estimated 150 000 seals (Hindell & Burton 1987), indicating poor agreement with the model.

they are corrected by allowing for 15.8% more seals that were unexploited, the new estimate becomes between 93 000 and 143 000.

Estimate of Population Size in 1913 and the Impact of Sealing in the 1900's

In 1913, a team of scientists from the Australasian Antarctic Expedition (AAE) spent a year on Macquarie Island (Cumpston 1968). During this time they estimated that approximately 25 000 seals were ashore in the 1913 breeding season. Assuming this was a count of all the seals, male and female, with a sex ratio of 1:11 (Hindell & Burton 1987), there must have been approximately 23 000 females ashore. This figure can be used, in turn, to estimate total population size by multiplying by 3.5 (McCann 1985, Hindell & Burton 1987) and yields a total population size of around 88 000. A population of this size would produce an annual surplus of approximately 660 males, which is precisely the average number of seals removed each year (table 1).

The model predicted that a pre-sealing population of 117 000 seals, or 139 500 correcting for the unexploited west coast animals, would have recovered from a low of 54 000, after the heavy exploitation of the first sealing phase, to a population of around 63 000 by the time sealing resumed in 1875, and would have reached the observed level of 88 000 by 1913 (fig. 4). When the model was allowed to continue through until the end of 1959,

TABLE 2

Total population size and estimated numbers taken by sealers, 1810–29, for the initial population size of 100 000

Date	Population Size	Number of Males Taken	Number of Females Taken
1809	100 000	0	0
1810	95 246	375	0
1811	95 779	1435	0
1812	96 149	710	0
1813	96 412	420	0
1814	96 607	400	0
1815	97 007	455	0
1816	97 477	280	0
1817	97 965	550	0
1818	98 318	255	0
1819	98 697	325	0
1820	99 115	2310	0
1821	82 123	3065	0
1822	71 964	1610	0
1823	51 334	2189	11 418
1824	50 301	945	0
1825	47 392	1530	0
1826	34 319	2431	2202
1827	26 183	1824	2028
1828	31 707	255	0
1829	33 307	615	0
Total		21 979	15 648

when there are good island-wide counts, the theoretical population only reached 92 000, compared to the observed 156 000 (Hindell & Burton 1987).

DISCUSSION

It should be stressed, at the outset, that the conclusions discussed here are based on estimates, and in some cases quite broad estimates. The records derived from the sealers' activities, and hence our calculated oil yields, were often sketchy; much of the information used to formulate the population model was based on assumptions that are difficult to test. Despite this, we consider that the results still form a useful framework for some speculations on the past impact of sealing on Macquarie Island's elephant seal population.

The History of the Elephant Seal Industry on Macquarie Island

The shipping records appear to be essentially complete, and clearly demonstrate that the sealing effort at Macquarie island was far from constant over the 106 years that the elephant seal population was exploited. The first 20 years saw the most intensive sealing activity. Almost half of all the sealing voyages occurred between 1811 and 1829. It is apparent from the estimated annual oil yield during this time that for the first ten years (1810–19) the sealers paid relatively little attention to the elephant seals. Initially the sealers were attracted to Macquarie Island, not for the elephant seal oil, but for the more profitable fur seal skins (Cumpston 1968). Further, the existence of a British Government duty on colonial oil (Cumpston 1968) probably discouraged exploitation of elephant seals. It is likely that the lifting of this duty in 1820 was linked with the beginning of the most intensive period of exploitation.

Approximately 4428 tuns of the total 8280 tuns of oil collected were removed in the next ten years. Thus, this relatively brief period would have seen the major impact on the population. This is supported by the observation that there was a steady decline in the return per unit sealing effort during this ten-year period.

The population would have increased during the 45 years following 1830, when there was little or no sealing activity. When sealing did resume, in 1875, it was at a fairly low level and seems to have been opportunistic, with an average of only 46 tuns of oil collected annually. Under the Hatch administration (1890–1919) there were usually three visits to the island annually, removing approximately 660 seals. Towards the end of this period, in 1913, the population was about 88 000 and producing an annual surplus of about 660, so the level of sealing at this time was unlikely to lead to long-term population decline.

If most of the seals killed from 1870 onwards were males, approximately 14 100 seals (2820 tuns at 0.2 tuns per male) would have been killed in this period. Combined with the estimated 38 000 seals, both males and females, killed between 1810 and 1829 (table 2) this gives a total of approximately 52 000 seals killed during the 109 years of exploitation on Macquarie Island. This is far fewer than the 300 000 seals estimated by Busch (1985), and suggests that his estimate of the total world-wide harvest of 1 000 000 southern elephant seals may be too high.

Estimates of Pre-Sealing Population Size

The model of the exploited elephant seal population defined the initial size of the population at Macquarie Island as approximately 93 000–143 000 in order to sustain the level of sealing during the first two decades of exploitation. This presumes that all of the assumptions of the model hold, and that the observed decline in the amount of oil removed per ship between 1820 and 1830 really does reflect a decline in the return for similar sealing effort.

The model required an initial population size of 139 500 seals to produce a population of 88 000 in 1913, and predicted a fairly slow and constant rate of increase between 1830 and 1875 (fig. 4). However, northern elephant seals (*Mirounga angustirostris*) exhibited exponential population growth when sealing was stopped (Bartholomew & Hubbs 1960) and similar exponential growth has been reported for fur seal populations when sealing ceased (Payne 1978). Also, the Macquarie Island elephant seal population displayed much more rapid growth between 1919 and 1959 than was predicted by the model, suggesting that our model is inadequate in describing the increase phase of an elephant seal population. A possible problem with the model is use of age-specific mortalities from the stable South Georgia population. These data would have been adequate for the model during the times that the population was under exploitation, although the annual recruitment may have been overestimated. The population increase at Macquarie Island may have been due to changes in

several population parameters, such as an increase in fecundity, reduced mortality in some or all age classes, or a change in the age at first breeding. Many of these processes are density dependent, and the failure of the model to incorporate them will result in underestimation of the rate of recovery and so overestimation of the initial population size. Unfortunately, there is no life history data available for southern elephant seals during a recovery phase, so it is difficult to know how the models should be adjusted to enable more accurate predictions. Thus, an initial population size of 139 500 could be an overestimate, and the initial population size of the Macquarie Island seals may be closer to the lower limits of the range, that is around 93 000–110 000.

This suggests that, by 1913, the population had recovered to near the pre-sealing levels. Perhaps the level of sealing after 1890 was sufficient to maintain the population at just below the pre-sealing levels, allowing the seals prey (thought to be fish and squid, Laws 1960) to increase to higher than normal levels. With the end of sealing, the population may have expanded beyond the pre-sealing levels to the high levels observed in the 1950's, due to an abundance of food. The recently described decline in elephant seal numbers at Macquarie Island (Hindell & Burton 1987) may be a result of the population returning to equilibrium. However, when the exploitation of the South Georgia elephant seal population ceased in 1964, after over a century of sealing (Laws 1981), there was no subsequent increase in population size over the next 25 years (McCann, pers. comm.). In the later years, at least, the South Georgia elephant seal industry was carefully managed to ensure the number of males removed did not exceed the annual surplus (Laws 1960), as may have been the case at Macquarie Island between 1890 and 1916 (although it is unlikely that this was a deliberate policy). The reasons for the different responses of the two populations are unclear but may reflect differences between them in fundamental ecological parameters. More information on these parameters, such as specific life history data for the Macquarie Island population, will be necessary to resolve this question.

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REFERENCES

ALLEN, K.R. & KIRKWOOD, G.P., 1978: Simulation of Southern Hemisphere sei whale stocks. *Rep. Int. Whal. Comm.*, 28: 151–157.

BARTHOLOMEW, G.A. & HUBBS, C.L., 1960: Population growth and seasonal movements of the northern elephant seal, *Mirounga angustirostris*. *Mammalia*, 24: 313–324.

BEDDINGTON, J.R. & KIRKWOOD, G.P., 1980: On the mathematical structure of possible sperm whale models. *Rep. Int. Whal. Comm.*, Special Issue, 2: 57–58.

BRYDEN, M.M., 1968: Growth and function of the subcutaneous fat of the elephant seal. *Nature*, 220: 597–599.

BRYDEN M.M. & STOKES, G.B., 1969: Metabolism of fatty acids in the southern elephant seal *Mirounga leonina* L. *Can. J. Biochem.*, 47: 757–760.

BUSCH, B.C., 1985: *THE WAR AGAINST THE SEALS*. Gill-Queens University Press, Canada.

CARRICK, R. & INGHAM, S.E., 1962a: Studies of the Southern elephant seal, *Mirounga leonina* (L.). I. Introduction to the series. *CSIRO Wildl. Res.*, 7: 89–101.

CARRICK, R. & INGHAM, S.E. 1962b: Studies of the Southern elephant seal, *Mirounga leonina* (L.). V. Population dynamics and utilization. *CSIRO Wildl. Res.*, 7(2): 198–206.

CARRICK, R., CSORDAS S.E. & INGHAM, S.E., 1962: Studies of the southern elephant seal, *Mirounga leonina* (L.). IV. Breeding and development. *CSIRO Wildl. Res.*, 7: 161–197.

CUMPSTON, J.S., 1963: *SHIPPING ARRIVALS AND DEPARTURES. VOL. I SYDNEY 1788–1825*. Roebuck, Canberra.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser.A(1), 93: 1–380.

GALES, N.J. & BURTON, H.R., 1987: Ultrasonic measurement of blubber thickness of the southern elephant seal *Mirounga leonina* (L.). *Aust. J. Zool.*, 35.

GRIFFITHS, D.J., 1984: The annual cycle of the testis of the elephant seal (*Mirounga leonina*) at Macquarie Island. *J. Zool. (Lond.)*, 203: 193–204.

HAMILTON, J.E., 1949: Weight etc., of elephant seal. *Nature*, 163: 536.

HAMILTON, R., 1839: *THE NATURAL HISTORY OF THE AMPHIBIOUS CARNIVORA, INCLUDING THE WALRUS AND SEALS, ALSO OF THE HERBIVOROUS CETACEA, ETC.* W.H. Lizars, Edinburgh.

HINDELL, M.A. & BURTON, H.R. (1987): The past and present status of the southern elephant seal *Mirounga leonina* (Linn.) at Macquarie Island. *J. Zool. (Lond.)*, 213.

JONES, E., 1981: Age in relation to breeding status of the male southern elephant seal, *Mirounga leonina* (L.), at Macquarie Island. *Aust. Wildl. Res.*, 8: 327–334.

KEMP, P., 1976: *THE OXFORD COMPANION TO SHIPS AT SEA*. Oxford University Press, London.

KERR, I.S., 1976: *CAMPBELL ISLAND. A HISTORY*. A.H. and A.W. Reed Ltd, Wellington.

LAWS, R.M., 1960: The southern elephant seal (*Mirounga leonina* Linn.) at South Georgia. *Norsk Hvalfangst-Tidende*, 10, 11: 466–476, 520–542.

LAWS, R.M., 1981: Biology of Antarctic seals. *Sci. Prog. Ox.*, 67: 377–397.

LING, J.K. & BRYDEN, M.M., 1981: Southern elephant Seal *Mirounga leonina* Linnaeus, 1758. *In* Ridgeway, S.H. & Harrison, R.J. (Eds): *HANDBOOK OF MARINE MAMMALS*, Vol.2. Academic Press, London: 297–327.

McCANN, T.S., 1980: Population structure and social organization of southern elephant seals, *Mirounga leonina* (L.). *Biol. J. Linn. Soc.*, 14: 133–150.

McCANN, T.S., 1985: Size, status and demography of southern elephant seal *Mirounga leonina* populations. In Ling, L.K. & Bryden, M.M. (Eds): *SEA MAMMALS OF SOUTH LATITUDES. Proceedings of a symposium of the 52nd ANZAAS Congress*. South Australian Museum: 1–17.

NICHOLSEN, I.H., 1963: *SHIPPING ARRIVALS AND DEPARTURES. SYDNEY. Vol.II, 1826–1840*. Roebuck, Canberra.

NICHOLSEN, I.H., 1983: *SHIPPING ARRIVALS AND DEPARTURES. TASMANIA. Vol.I, 1803–1833*. Roebuck, Canberra.

NICHOLSEN, I.H., 1985: *SHIPPING ARRIVALS AND DEPARTURES. TASMANIA. Vol.II, 1834–1842*. Roebuck, Canberra.

PAYNE, M.R. 1978: Population size and age determination in the Antarctic Fur seal *Arctocephalus gazella. Mamm. Rev.*, 8: 67–73.

SCAMMON, C.M., 1874: *THE MARINE MAMMALS OF THE NORTH-WESTERN COAST OF NORTH AMERICA. Described and Illustrated. Together With an Account of the American Whale-fishery*. John H. Carmany and Co., San Francisco.

SHAUGHNESSY, P.D. & BEST, P.B., 1982: A discrete population model for the South African fur seal *Arctocephalus pusillus pusillus. In MAMMALS OF THE SEAS*, FAO Fisheries Series.

WINTER, G. & NUNN, W.J., 1950: The component fatty acids of elephant seal oil: the distribution in the body. *J. Sci. Food Agr.*, 10: 311–314.

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APPENDIX

A complete shipping list of all vessels to call at Macquarie Island between 1810 and 1919. Compiled from Cumpston (1963, 1968), Nicholsen (1963, 1983, 1985).

Vessel	Departure Date	Port Departure	Arrival Date	Region	Departure Date	Port Return	Return Date	Cargo
Perseverance	25. 6.1810	Sydney	11. 7.1810		18. 7.1810	Sydney	17. 8.1810	
Perseverance	7. 9.1810	Sydney	2. 10.1810		17.10.1810	Sydney via Campbell Is	8. 1.1811	Some oil. 70 tuns?
Elizabeth & Mary	21. 10.1810	Sydney	31.12.1810			Sydney	2. 3.1811	19 950 fur seal skins
Unity	15. 9.1810	Sydney	?. 12.1810		?. 3.1811	London		Fur seal skins
Sydney Cove	?. ?.1810	Sydney	?. 12.1810			Sydney	13. 3.1811	Skins and whale oil
Aurora	18. 9.1810	Sydney			?.12.1810	Sydney via Campbell Is	29.12.18101	40 gallons (all from Macquarie Is?)
Aurora	9. 2.1811	Sydney				Sydney	11. 5.1811	60 tuns elephant oil
Concord	9. 3.1811	Sydney	1. 4.1811			Sydney	1. 5.1811	No cargo
Governor Bligh	4. 5.1811	Sydney				Sydney	7.11.1811	?
Mary & Sally	18. 5.1811	Hobart	mid 1811			Sydney	27.11.1811	?
Concord	1. 6.1811	Sydney	12. 7.1811	Blown off for six weeks	5. 8.1811	Sydney	1.10.1811	No cargo
Perseverance	9. 6.1811	Sydney	25. 9.1811			Sydney	31.10.1811	Skins
Sydney Cove	21. 9.1811	Sydney			11. 3.1812			70 tuns oil, 11 000 skins
Cumberland	28.11.1811	Sydney			20.12.1811	Sydney via Campbell Is	3. 7.1812	25 tuns oil, 900 skins
Concord	14.11.1811	Sydney	10. 1.1812	West coast	10. 3.1812	London		50 tuns oil, 13. 700 skins
Governor Bligh	28.11.1811	Sydney	20.12.1811		24. 2.1812	Sydney	7. 6.1812	14 tuns oil, 4000 skins
Mary & Sally	15. 2.1812	Sydney	20. 3.1812			Sydney	21. 7.1812	80 tuns whale oil
Perseverance	23. 2.1812	Sydney	18. 3.1812		7. 4.1812	Sydney	7. 5.1812	65 tuns oil, 9000 skins
Perseverance	4. 7.1812	Sydney			13. 10.1812	Sydney	31.10.1812	40 tuns oil, 15 000 skins
Governor Bligh	1. 9.1812	Sydney				Sydney	15.12.1812	3 tuns oil, 14 000 skins
Perseverance	11.12.1812			No further record				
Campbell Macquarie	21. 5.1812	Kangaroo Is	10. 6.1812	Wrecked				
Elizabeth & Mary	7.11.1812	Sydney				Sydney	28. 1.1813	17 000 skins
Mary & Sally	16.11.1813	Sydney	30.11.1813	Isthmus and Sandy Bay	19. 2.1814	Hobart	10. 4.1813	251 casks & 20 138 gallons
Elizabeth & Mary	4. 9.1814	Sydney				Sydney	6.12.1814	
Spring	20.10.1814	Hobart		Forced back		Sydney	6.12.1814	
Cumberland	6.12.1814					Sydney	26. 3.1815	44. 5 tuns oil
Endeavour	6.12.1814	Sydney				Sydney	9. 3.1815	31. 5 tuns oil
Betsey	28.12.1814	Sydney	13. 2.1815					0?

Vessel	Departure Date	Port Departure	Arrival Date	Region	Departure Date	Port Return	Return Date	Cargo
Elizabeth & Mary	14. 1.1815	Sydney		Via Campbell Is		Sydney	3. 3.1815	2690 skins
Betsey	?. 8.1815	Sydney		Did not arrive				
Cumberland	24. 6.1815	Sydney						
Elizabeth & Mary	8. 8.1815	Sydney				Sydney	11.11.1815	40 tuns oil
Elizabeth & Mary	26. 3.1816	Sydney				Sydney	28. 5.1816	30 tuns oil, 1200 skins
Elizabeth & Mary	27. 9.1816	Sydney				Sydney	21. 1.1817	23. 5 tuns oil
Elizabeth & Mary	13. 7.1817					Sydney	1. 9.1817	20 tuns oil
Elizabeth & Mary	16.10.1817	Sydney				Sydney	26.11.1817	Cargo of oil
Campbell Macquarie	9.11.1817	Sydney				Sydney	9. 2.1818	52 tuns oil
Elizabeth & Mary	17.12.1817	Sydney				Sydney	10. 2.1818	14 tuns oil
Elizabeth & Mary	7. 3.1818	Sydney				Sydney	13. 7.1818	8. 8 tuns oil
Elizabeth & Mary	6. 8.1818	Sydney				Sydney	21.12.1818	26. 5 tuns oil
Governor Bligh	22. 8.1818			Via Campbell Is		Sydney	30. 3.1819	10516 skins
Elizabeth & Mary	25. 1.1819	Sydney		Via New Zealand		Sydney	2. 3.1819	17 tuns oil, 1243 skins
Elizabeth & Mary	23. 6.1819	Sydney				Sydney	1.11.1819	33 tuns oil, 3190 skins
Campbell Macquarie	12. 9.1819	Sydney				Sydney	3.12.1819	12 tuns oil
Elizabeth & Mary	8.12.1819	Sydney		Via New Zealand		Sydney	27. 1.1820	4397 skins
Elizabeth & Mary	12. 3.1820	Sydney				Sydney	11. 5.1820	30 tuns oil
Regalia	26. 8.1820	Hobart		South End		Sydney	21.10.1820	0?
Robert Quayle	8. 9.1820	Hobart		South End	13.11.1820	London		150 tuns
Regalia	1.12.1820	Sydney		South End		Hobart	1. 3.1821	260 tuns
Bellingshausen			28.11.1820					
Midas	10. 5.1821	Hobart		North End		Hobart	1. 8.1821	0
Emerald	12. 5.1821	Hobart		South End		Hobart	11. 9.1821	Live elephant seal
Elizabeth & Mary	6. 8.1821	Sydney		North End & Campbell Is		Sydney	?. 1.1822	
Surrey	5. 9.1821	Sydney	24. 9.1821	North End and Lusitania Bay	21.11.1821	Sydney	6.12.1821	180 tuns oil
Midas	27. 9.1821					Sydney	23. 1.1822	300 tuns oil
Emerald	7.11.1821	Hobart	16.11.1821	Lusitania Bay		Hobart	15. 6.1822	104 tuns oil
Lusitania	14. 2.1822	Hobart	?. 3.1822			London		30 tuns oil
Elizabeth & Mary	5. 5.1822	Sydney		North End		Sydney	4. 9.1822	50 tuns oil
Emerald	13. 9.1822	Hobart		South End		Hobart	31.10.1822	150 tuns oil
Mariner	26. 9.1822	Sydney				Sydney	10.12.1822	262 tuns (or. 77 tuns*)

Elizabeth & Mary	21. 1.1823	Sydney		North End		Sydney	25. 3.1823	51 tuns oil
Lynx	28. 1.1823	Sydney		North End		Sydney	18. 7.1823	150 tuns (15 tuns*)
Regalia	13. 3.1823	Sydney				Sydney	29. 5.1823	282 tuns oil
Wellington	1. 4.1823	Sydney				Sydney	22. 9.1823	"Cargo of oil", 4000–5000 skins
Caroline	17. 4.1823	Hobart		South End		Hobart	11. 7.1823	"Cargo of oil"
Elizabeth & Mary	26. 4.1823	Sydney		Via Campbell Is		Sydney	23. 9.1823	6 tuns oil, 814 skins
Perseverance	16. 9.1823	Sydney		North End		Sydney	30.10.1823	60 tuns oil
Caroline	25. 9.1823	Hobart		South End		Sydney	1. 1.1824	180 tuns oil
Wellington	10.10.1823	Sydney				Sydney	3. 4.1824	Skins only
Elizabeth & Mary	29.10.1823	Sydney		Via Campbell Is		Sydney	17. 3.1824	10 tuns oil, 3500 skins
Midas	22.12.1823	Sydney				Sydney	7. 2.1824	330 tuns oil
Caroline	4. 4.1824	Sydney		South End		Sydney	22. 4.1824	90 tuns oil
Perseverance	21. 9.1824	Sydney		North End		Sydney	23. 2.1825	0?
Caroline	17.11.1824	Sydney	15. 2.1825	Wrecked 17. 2.1825				160 tuns oil
Cypress	17. 8.1825	Hobart	17. 9.1825	South End		Hobart	1.10.1825	66 tuns oil
Wellington						Sydney	18. 9.1825	100 tuns oil, 1800 skins
Wellington	26 10.1825	Sydney		North End		Sydney	22.12.1825	65 tuns oil
Perseverance	24.10.1825	Sydney		North End		Sydney	27.12.1825	60 tuns oil
Elizabeth & Mary	10. 1.1826	Sydney		Via New Zealand		Sydney	3. 6.1826	7 tuns oil, 4000 skins
Perseverance	6. 2.1826	Sydney		North End		Sydney	2. 4.1826	60 tuns oil
Brutus	9. 3.1826	Sydney			12. 4.1826			200 tuns oil
Lord Rodney	4. 5.1826	Sydney				Sydney	26. 6.1826	120 tuns oil
Elizabeth & Mary	14. 7.1826	Sydney		Via New Zealand		Sydney	12. 3.1827	10 tuns oil, 300 skins
Sydney Packet	18. 8.1826	Sydney		Caroline Cove		Sydney	23.10.1826	"Cargo of oil"
Perseverance	11. 9.1826	Sydney				Sydney	3.12.1826	76 tuns oil
Lord Rodney	15.11.1826	Sydney	22.12.1826	Caroline Cove		Sydney	21.12.1826	"Cargo of oil"
Sydney Packet	1. 1.1827	Hobart		West Coast		Hobart	25. 2.1827	56 tuns oil
Perseverance	2. 1.1827	Sydney				Sydney	14. 3.1827	70 tuns oil
Lord Rodney	23. 1.1827				1. 3.1827	Sydney	21. 3.1827	100 tuns oil
Elizabeth & Mary	13. 4.1827			Via New Zealand	1. 6.1827	Sydney	20. 6.1827	"Skins and oil"
Elizabeth & Mary	2. 8.1827	Sydney						
Perseverance	20. 8.1827	Sydney		North End	25. 9.1827	Sydney	10.12.1827	11 tuns oil (18 tuns*)
Governor Arthur	11. 9.1827	Sydney		South End		Sydney	1.11.1827	15 tuns oil
Perseverance	8.11.1827	Sydney				Sydney	7. 2.1828	70 tuns oil
Rolls	11.11.1827	Sydney				London		?
Governor Arthur	6.12.1827	Sydney			17. 1.1828	Sydney	7. 2.1828	8 tuns oil

Vessel	Departure Date	Port Departure	Arrival Date	Region	Departure Date	Port Return	Return Date	Cargo
Elizabeth & Mary	9. 6.1828	Sydney		Via New Zealand		Sydney	7. 9.1828	"Oil and skins"
Elizabeth & Mary	6.12.1828	Sydney		Via New Zealand		Sydney	7. 4.1829	"Oil and skins"
Blues	19. 4.1828	Sydney		South End		Rio de Janiero		?
Elizabeth & Mary	20. 5.1829	Sydney		Via New Zealand		Sydney	23. 9.1829	18 tuns oil, 330 skins
Faith	22.12.1829	Sydney		South End		Sydney	18. 4.1830	60 tuns oil (left 120 tuns)
Venus	early 1831	Sydney						0 tuns
Eleanor	19. 3.1834	Sydney				Sydney	7. 6.1834	1 cask
Bree (Bee?)	16.11.1834	Hobart				Sydney	20.12.1834	0 tuns
Bree (Bee?)		Sydney				Sydney	19. 5.1835	0 tuns
Enderby expedition			?. ?.1837					"Large number of skins"
Lord Nelson			?. ?.1838	Wrecked				
Peacock		USA	10.10.1840	South End				0
Flying Fish		USA	10.10.1840	South End				0
Lord Duncan	?. ?.1851	Auckland Is	3.12.1851	Isthmus				147 elephant seals killed
Countess of Minto	4.11.1851	Sydney	3.12.1851	Wrecked at the Nuggets				
Brisk			5. 4.1852					?
Sarah Pile	11.10.1873	Invercargil	17.11.1873				20. 1.1874	0
Spirit of the Sth	?. ?.1874	Adelaide	20. 6.1874	Caroline Cove				0
Chance	13. 9.1874	Invercargil					5.11.1874	?
Chance	?. ?.1874					Invercargil	11. 1.1875	50 tuns sperm & elephant oil
Splendid						Invercargil	1. 4.1875	43 tuns & 105 casks oil
Splendid	12. 7.1876	Dunedin		Isthmus		Dunedin	?. 9.1876	?
Splendid	13.12.1876	Pt William	26.12.1876					65 tuns oil
Bencleugh	10. 7.1877	Pt Chambers	27. 7.1877	Wrecked on North Head				15 tuns
Friendship	?. ?.1877		20. 8.1877					
Friendship	9.11.1877	Stewart Is	27.11.1877					
Jessie Nichol	29.12.1877	Dunedin			29. 1.1878	Dunedin	13. 2.1878	16 casks oil

Jessie Nichol	25. 7.1878	Otago	14. 8.1878		1. 9.1878	Otago	3. 9.1878	18 tuns
Jessie Nichol	12. 9.1878	Dunedin				Dunedin	30.10.1878	?
Jessie Nichol	7. 2.1879						?	
Jessie Nichol	17. 5.1879		23. 5.1879	Isthmus & Sandy Bay		Otago	22. 6.1879	0?
Jessie Nichol	23.11.1879		1.12.1879	West Coast & Isthmus			27.12.1879	40 casks
Jessie Nichol	6. 3.1880						8. 4.1880	25 tuns (left 60 tuns)
Jessie Nichol	21. 4.1880			Lusitania Bay & Hurd Pt?			1. 6.1880	?
Jessie Nichol	3.11.1880			Lusitania Bay & Isthmus			15.12.1880	55 tuns
Jessie Nichol	13. 1.1881			Lusitania Bay & Hurd Pt			18. 2.1881	48 tuns
Jessie Nichol	29. 4.1881						8. 6.1881	18 tuns
Jessie Nichol	11. 1.1882						13. 2.1882	15 casks
Jessie Nichol	6. 3.1882						16. 5.1882	"Cargo of oil"
Jessie Nichol	3. 1.1883						16. 2.1883	35 tuns oil
Sarah W. Hunt	?. ?.1883		?.11.1883					0
Jessie Nichol	19. 7.1884			Isthmus			21.12.1884	40 tuns
Janet Ramsey	18.11.1887		7.12.1887		18. 1.1888			9 tuns
Awarua	2.12.1887	Invercargil				Invercargil	27. 2.1888	?
Janet Ramsey	28. 2.1888		7. 4.1888				9. 4.1888	"Cargo of oil"
Awarua	24. 3.1888	Invercargil	14. 4.1888	North and South Ends		Invercargil	3. 7.1888	35 casks (& 10 tons lost)
Janet Ramsey	6.10.1888	Invercargil	11.11.1888					24 tuns
Awarua	29.10.1888	Invercargil				Invercargil	28.12.1888	0
Janet Ramsey	24. 1.1889	Pt Chambers	1. 2.1889	Could not land				
Awarua	29. 1.1889	Invercargil				Invercargil	4. 3.1889	"Cargo of oil"
Awarua	6. 6.1889	Pt Chambers	25. 6.1889			Invercargil	17. 7.1889	"Cargo of oil"
Janet Ramsey	11. 9.1889	Pt Chambers	1.10.1889	East, north & northwest coasts	Pt Chambers	27.12.1889	10 tuns	
Awarua	29.11.1889	Invercargil	6.12.1889	Isthmus & Lusitania Bay	25.12.1889			35 tuns
Awarua			20. 4.1890	Lusitania Bay?	1. 5.1890	Invercargil	12. 5.1890	3 tuns penguin oil

Vessel	Departure Date	Port Departure	Arrival Date	Region	Departure Date	Port Return	Return Date	Cargo
Kakanui	24.12.1890	Invercargil	2. 1.1891	Lusitania Bay	2. 1.1891			18–20 tuns elephant & penguin oil
Gratitude	15. 1.1891	Invercargil	2. 2.1891			Invercargil	18. 3.1891	?
Hinemoa	22. 1.1891	Invercargil	29. 1.1891			Invercargil	6. 2.1891	0?
Gratitude	?.10.1891					Invercargil	18.12.1891	Penguin oil
Gratitude	7. 1.1892	Invercargil	25. 1.1892					Penguin oil
Gratitude	29.10.1892	Dunedin	15.11.1892				6.12.1892	?
Gratitude			9. 1.1893					17 tuns penguin oil
Gratitude	2. 4.1893	Invercargil	23. 4.1893	Nuggets				30 tuns penguin oil
Gratitude	5. 8.1893		25. 8.1893	Lusitania Bay	12. 9.1893	Invercargil	21. 9.1893	"Cargo of oil"
Gratitude	14.12.1893	Invercargil	17.12.1893		28.12.1893	Invercargil	2. 1.1894	"Cargo of oil"
Gratitude	22. 2.1894	Invercargil	11. 3.1894	Nuggets	23. 3.1894	Invercargil	31. 3.1894	Penguin oil?
Gratitude	10. 5.1894	Invercargil	26. 5.1894		3. 6.1894			"Cargo of oil"
Gratitude	26. 8.1894			Via Auckland Is?			1.11.1894	24 casks blubber, 500 skins
Antarctic	3.10.1894	Hobart	20.10.1894	Could not land				
Gratitude	6.12.1894		31.12.1894		2. 1.1895			Skins only
Gratitude	13. 2.1895	Invercargil				Invercargil	31. 3.1895	269 casks penguin oil
Gratitude	26. 8.1895	Invercargil	25. 9.1895		3.10.1895			?
Gratitude	1. 1.1896	Invercargil	13. 1.1896		12. 2.1896			60 tuns elephant & penguin oil
Gratitude	19. 9.1896	Invercargil	11.10.1896		28.10.1896	Invercargil	1.11.1896	35 tuns left
Gratitude	2.11.1896		28.11.1896				31.12.1896	30 tuns oil
Gratitude	23. 1.1897	Invercargil				Melbourne	9. 3.1897	54 tuns oil
Gratitude	23. 3.1897	Melbourne			20. 4.1897	Pt Chambers	24. 4.1897	"Cargo of oil"
Gratitude	26. 8.1897	New River	6. 9.1897	Lusitania Bay		Invercargil	13.12.1897	0
Gratitude	23.12.1987	Invercargil	3. 1.1898		9. 1.1898	Invercargil	26. 1.1898	20 tuns oil
Gratitude	28. 2.1898		11. 3.1898		1. 4.1898	Pt Chambers	14. 4.1898	"Cargo of oil"
Gratitude	29. 4.1898	Invercargil	22. 5.1898	Nuggets	8. 6.1898			"Cargo of oil"
Gratitude	11.10.1898	Invercargil	28.10.1898	Nuggets-beached				
Tutanekai			17. 2.1899		19. 2.1899			263 casks oil
Annie Hill	12. 4.1899	Dunedin		Nuggets		Invercargil	23. 6.1899	?
Annie Hill	4. 7.1899	Invercargil	19. 7.1899	Nuggets and Lusitania Bay	19. 8.1899	Invercargil	23. 8.1899	509 casks oil

Carin	17. 2.1900	Launceston		Unable to land				
Hinemoa	7. 4.1900	Invercargil					27. 4.1900	"Cargo of oil"
H M Ringdove			?.12.1900				27. 4.1900	0
Discovery			22.11.1901					0
Tutanekai			13. 1.1902					40 tuns oil
Enterprise	3. 9.1902	Otago	12. 9.1902		21.10.1902	Pt Chambers	28.11.1902	0
Enterprise	24.12.1902	Pt Chambers		Could not land		Pt Chambers	17. 2.1903	0
Enterprise	18. 4.1903	Dunedin	9. 5.1903	Nuggets		Otago	30. 5.1903	60 tuns oil
Jessie Nichols	4. 9.1905	Pt Chambers	13. 9.1905			Pt Chambers	14.10.1905	0
Jessie Nichols	4.12.1905					Invercargil	28.12.1905	Penguin oil
Jessie Nichols	?. 2.1906		?. 8.1906				3. 9.1906	50 tuns oil
Jessie Nichols	12. 8.1907	Dunedin	27. 8.1907		18. 9.1907	Invercargil	7.10.1907	53 casks oil
Jessie Nichols	11.11.1907						13.12.1907	?
Jessie Nichols	3. 2.1908	Invercargil				New River	6. 3.1908	306 casks oil
Jessie Nichols	30.11.1908	Invercargil	16.12.1908	Nuggets	6. 1.1909			0?
Jessie Nichols					17. 3.1909			56 tuns oil
Nimrod			25. 5.1909		30. 5.1909			0
Jessie Nichols			9. 8.1909		21. 8.1909		3. 9.1909	0?
Jessie Nichols	24. 9.1909						3.11.1909	"Cargo of oil"
Jessie Nichols			10.12.1909				27.12.1909	"Cargo of oil"
Jessie Nichols	20. 1.1910	Invercargil	8. 2.1910		12. 2.1910	Invercargil	18. 2.1910	?
Jessie Nichols	8. 3.1910			Unable to reach Macquarie Is				0
Hinemoa	22. 7.1910	Invercargil	25. 7.1910	Nuggets			28. 7.1910	Oil from 675 elephant seals
Jessie Nichols	18. 8.1910						19.10.1910	
Jessie Nichols	8.12.1910	Invercargil	18.12.1910	Wrecked Sandy Bay				0
Ida M. Clarke			early 1911					0
Huanui	11. 3.1911	Invercargil						?
Clyde	28. 9.1911	Wellington		Wrecked Buckles Bay				0
Toroa	9.12.1911	Hobart						0
Aurora			11.12.1911		23.12.1911			0
Toroal			3.12.1911					300 casks elephant seal oil

Vessel	Departure Date	Port Departure	Arrival Date	Region	Departure Date	Port Return	Return Date	Cargo
Aurora	17. 5.1912		6. 7.1912					0
Rachel Cohen	1. 9.1912	Hobart	8. 9.1912		8.10.1912			116 barrels elephant seal oil
Aurora			2.11.1912		25.11.1912			?
Rachel Cohen			2. 1.1913		5. 2.1913	Hobart	1. 3.1913	216 barrels penguin oil
Rachel Cohen	5. 7.1913	Hobart		Unable to reach Macquarie Island				0
Tutanekai			20. 8.1913		22. 8.1913			0
Rachel Cohen	28.10.1913	Dunedin	8.11.1913		28.11.1913	Hobart	14.12.1913	460 casks oil
Aurora	19.11.1913	Hobart	28.11.1913					0
Rachel Cohen	30.12.1913	Hobart?			21. 1.1914	Hobart	4. 2.1914	420 barrels oil
Rachel Cohen			?.11.1914			Pt Chambers	4.11.1914	"Oil and skins"
Endeavour	25.11.1914	Hobart	29.11.1914		3.12.1914			0
Aurora	25.12.1914	Hobart	30.12.1914		31.12.1914			0
Grantala			7. 1.1915		?. 1.1915	Hobart	18. 8.1915	0
Rachel Cohen	?.10.1914	Dunedin	29.11.1915			Invercargil	13.12.1915	43 barrels oil
Rachel Cohen	30. 1.1916	Invercargil				Invercargil	29. 2.1916	?
Rachel Cohen	27. 5.1916	Invercargil	5. 6.1916			Invercargil	5. 7.1916	0
Rachel Cohen	26. 9.1916	Invercargil	10.10.1916		29.10.1916	Invercargil	4.11.1916	3. 5 tuns oil
Rachel Cohen	9.12.1916		31.12.1916		12. 1.1917	Hobart	2. 2.1917	470 barrels oil
Rachel Cohen	30.10.1917	Hobart				Hobart	1.12.1917	216 barrels oil
Rachel Cohen	11. 7.1917	Invercargil			16.11.1917			?
Rachel Cohen	19.12.1917	Hobart	25.12.1917		22.12.1917			?
Rachel Cohen	22. 1.1918	Invercargil	8. 2.1918					299 casks elephant oil?
Tutanekai			28. 4.1918		10. 5.1918			?
Rachel Cohen	19. 9.1918	Invercargil	9.10.1918	Nuggets	2.11.1918	Hobart	19.11.1918	486 casks penguin oil
Rachel Cohen	10.12.1918	Hobart				Hobart	30. 1.1919	550 barrels elephant blubber
Rachel Cohen	1. 4.1919					Invercargil		450 casks oil

RECOVERY OF THE FUR SEAL POPULATION AT MACQUARIE ISLAND

by P. D. Shaughnessy, G. L. Shaughnessy and L. Fletcher

(with four tables, six text-figures and two plates)

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Fur seals at Macquarie Island were harvested indiscriminately from the time of its discovery in July 1810 until the supply of animals was exhausted. The identity of the original fur seal is unknown and no specimens exist.

The New Zealand fur seal *Arctocephalus forsteri* has been recorded at the island since 1948 when Australian National Antarctic Research Expeditions (ANARE) began there. Numbers have increased slowly to about 1200 animals, most of them on North Head peninsula. The species is present throughout the year but does not breed on the island.

Breeding colonies of the subantarctic and antarctic fur seals, *A. tropicalis* and *A. gazella*, were first recognised in Goat Bay and Secluded Beach on North Head peninsula in 1981–82. These species can generally be distinguished from each other and *A. forsteri* on the basis of external characters and vocalisations. *A. tropicalis* has not previously been reported as breeding in Australian waters; *A. gazella* breeds also at Heard Island.

In the 1985–86 and 1986–87 summers, the two groups of fur seals (non-breeders and breeders) were equally prevalent on North Head peninsula until late December, when numbers of the non-breeders increased markedly and numbers of the breeders decreased slightly.

In these two summers 30 and 37 pups were recorded. In 1986–87, the median pupping date was 10 December. Pups were born in six territories, four of which were held for most of December by *A. tropicalis* bulls and contained 86% of the pups. *A. gazella* bulls were smaller than *A. tropicalis* bulls. Almost all of the cows were identified as *A. gazella*, only a few *A. tropicalis* cows being recognised.

Key Words: fur seals, subantarctic fur seals, antarctic fur seals, New Zealand fur seals, Macquarie Island.

INTRODUCTION

In the last century, southern fur seals (*Arctocephalus* spp.) were severely overharvested at most subantarctic islands; at Macquarie Island they were exterminated ten or so years after the island was discovered in July 1810. The number of fur seals harvested there is unknown but, on the basis of shipping records documented by Cumpston (1968), Shaughnessy & Fletcher (1987) estimated that as many as 193 300 were taken.

The specific identity of the original fur seals is unknown, there being no specimens or records other than the sealers' name "upland seal". Three species are now found at the island, subantarctic (*A. tropicalis*), antarctic (*A. gazella*) and New Zealand (*A. forsteri*). Of these, the subantarctic fur seal is most likely to have been the original, but it is not impossible either that this one unknown species became extinct, or that there were two (or more) species at the island originally (Shaughnessy & Fletcher 1987).

Few fur seals were recorded at Macquarie Island in the period 1820 to 1948. Gwynn (1953) implied that small numbers were seen by the first ANARE party in 1948, and he recorded 50 in April 1949, which he identified as New Zealand fur seals.

An annual census has been conducted on North Head peninsula since 1950, showing a steady increase to between 800 and 1000 in the period 1982 to 1987. Newborn (black) pups were first seen in 1955 (Csordas & Ingham 1965) and were assumed to be *A. forsteri*. However, since the 1981–82 summer, it has been established that both the subantarctic fur seal and the antarctic fur seal are breeding on North Head peninsula, but that the New Zealand fur seal, while present in larger numbers, does not breed (Shaughnessy & Fletcher 1987).

Numbers of southern fur seals are recovering at many places, including Macquarie Island, but early stages of recovery have been little documented, especially the behavioural and social aspects. The opportunity for this is available at

FIG. 1 — Subantarctic islands where southern fur seals breed.

Macquarie Island. The long-term aim of the project of which this forms a part is to document the population growth of fur seals at the island and to ascertain the relative roles of the species involved. Aspects of the breeding biology of *A. gazella* and *A. tropicalis* in the 1985–86 and 1986–87 summers are described here; *A. forsteri* is discussed for comparative purposes and as it interacts with the two breeding species.

Elsewhere, the subantarctic fur seal breeds on islands north of the Antarctic Convergence in the South Indian and South Atlantic Oceans (fig. 1), particularly Gough, Marion, Amsterdam and the Crozet Archipelago. The antarctic fur seal breeds on island south of, or close to the Convergence, particularly at South Georgia, as well as Kerguelen and Heard. The New Zealand fur seal breeds in New Zealand, on its subantarctic islands, and on islands off the coast of South Australia and Western Australia (Bonner 1981).

METHODS

In the 1985–86 summer, Fletcher was present at Macquarie Island from 6 December until 14 March, and inspected the fur seals on North Head peninsula at intervals of one to two weeks. Field work by the other authors at Macquarie Island extended from 7 December 1986 to 27 January 1987.

In 1986–87, all fur seals on North Head peninsula were counted at weekly intervals. Breeding groups were visited at least three times per week, and numbers of animals were recorded in four categories: adult male, adult female, juvenile and pup. The adult male (bull) category included territory holders and large males that were resting or challenging. For *A. gazella*, small males were included in the bull category if they held a territory that included at least one cow and one pup, or if they challenged an *A. tropicalis* male that held a territory. The adult female class included animals with pups (i.e. cows), and animals of similar size and appearance that mixed with cows and were not driven away by bulls. Juveniles included animals smaller than cows, as well as males that were similar in size to cows but were chased away by bulls. Some animals on the fringe of territories were difficult to categorise, especially after mid-January. They were included in the juvenile class unless they had a pup or were the size of large cows. Use of the term "pup" is restricted to animals with a black natal coat; it is shed after 3–4 months.

In 1986–87, all pups and many of the adult males and adult females of the two breeding species were individually marked with combinations of yellow, blue and white oil-based paint (International Yacht Enamel). Because of wear, these marks had to be renewed at intervals of seven to ten days. Pups were weighed at similar intervals with 10 and 15 kg Salter spring balances.

A total of 64 fur seals, comprising 36 pups, 20 adult females, 5 juveniles and 3 young males, were tagged in 1986–87. Tags were applied to the trailing edge of both foreflippers of pups at about one month of age or when their weight exceeded 8 kg. Yellow plastic swivel tags (Jumbo Rototags) were used, inscribed with a four-digit number on each external surface and "Inform Antarctic Australia" on the internal surfaces. Other seals were also tagged on the foreflippers with the same series of tags, after it was ascertained that tagging would not cause undue disturbance. These animals were caught in a hoop net of 600 mm diameter with hessian inside the netting, and then restrained by one person.

SPECIES IDENTIFICATION

Species identification was based on pelage colour and pattern, facial profile, vocalisation, behaviour (particularly when approached by humans) and relative proportion of flippers to

A

B

PLATE 1

(A) Antarctic fur seal cow and (B) subantarctic fur seal cow, at Secluded Beach, Macquarie Island.

body length (Bonner 1968, Crawley & Wilson 1976, Condy 1978, Shaughnessy & Fletcher 1987).

Bulls

A. tropicalis bulls were easily recognised by their distinctive creamy-coloured chest and face. Small males of this species have similar coloration. Their most common vocalisation was a repeated deep growl, as described by Paulian (1964).

A. gazella bulls are uniformly grey to dark brown, and thus somewhat similar in appearance to *A. forsteri* bulls. However, pelage of the latter appears coarser and browner, and they have a longer, paler snout. In addition, the rhinarium is inflated and conspicuous in *A. forsteri* bulls, whereas it is smooth and inconspicuous in *A. gazella* (Bonner 1981). The most obvious distinction found between bulls of these two species was the habit of *A. forsteri* of growling and then fleeing when approached by humans; *A. gazella* bulls stood their ground and uttered rapid, wheezy exhalations which Bonner (1968) aptly described as whimpering. Vocalisations of *A. tropicalis* and *A. gazella* bulls were readily differentiated, as noted by Condy (1978) at Marion Island.

Cows

The pelage of cows of both *A. gazella* and *A. tropicalis* is variable in coloration (Condy 1978), but the present studies found *A. gazella* cows tended to be lighter in colour, and had longer, more visible external ears covered with white hair (plate 1A). Cows of both species were paler on the ventral surface than the dorsal surface.

The nose and face of A. *gazella* cows tend to be longer and sharper than those of *A. tropicalis* cows. The latter have a short, broad nose, reminiscent of a Pekinese dog, and concave in profile. In juvenile and small *A. gazella* the nose profile is convex, but it is slightly concave in larger *A. gazella* cows.

A useful feature for recognising large *A. tropicalis* cows is that the pale fur of the face extends above the eyes. Overall, large *A. tropicalis* cows have a similar pattern of coloration to bulls of the species (plate 1B).

Vocalisations are also useful for distinguishing between cows of the two species. In *A. gazella* the pup attraction call is higher pitched than the mournful wail of *A. tropicalis*. Cows of both species also have vocalisations similar to those of their bulls.

Pelage of *A. forsteri* cows has been described as uniformly brown (Crawley & Wilson 1976). No cows fitting that description were seen in breeding territories at Macquarie, but seals of that coloration were seen elsewhere on North Head peninsula. They may have been cows (or juveniles) of *A. forsteri*, but they were not breeding.

Pups

Head shape and pelage coloration of pups of *A. gazella*, *A. tropicalis* and *A. forsteri* have been discussed by Shaughnessy & Fletcher (1987). In brief, pups of *A. gazella* have a broad, flat head,

PLATE 2

Pups of the antarctic (left) and subantarctic (right) fur seal at Secluded Beach, Macquarie Island.

blunt snout and whitish muzzle, and the rest of the pelage is grizzled also. *A. forsteri* pups have a white muzzle, but their head profile is rounded. Pups of *A. tropicalis* have black pelage, including a black muzzle. At Macquarie Island, the differences in pelage and muzzle coloration between *A. gazella* and *A. tropicalis* became more apparent after the pups were a month old (plate 2).

No pups at Macquarie were recognised as having the characteristics of *A. forsteri.*

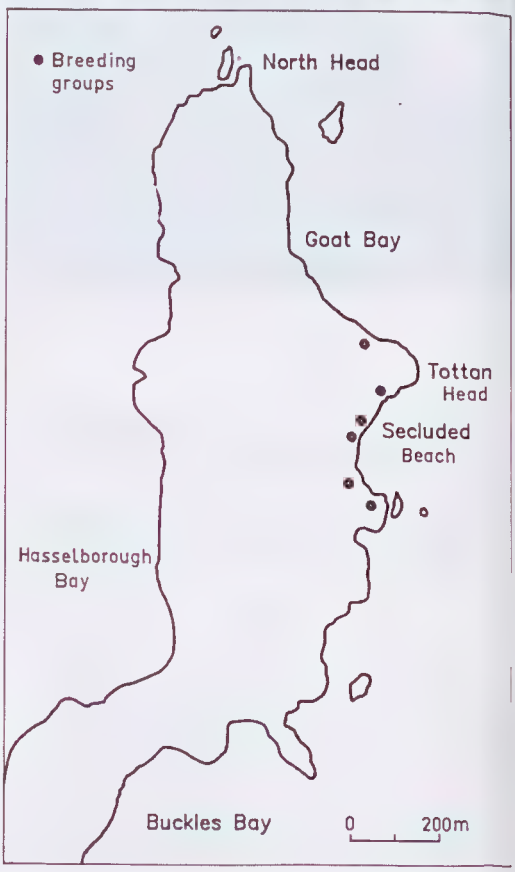

FIG. 2 — Map of North Head peninsula, Macquarie Island, showing localities where fur seals haul out.

HAULOUT LOCALITIES

Most *A. forsteri* were seen on North Head peninsula, particularly at North Head and Goat Bay. None was recorded in breeding territories of *A. gazella* and *A. tropicalis*. The main concentrations of *A. gazella* and *A. tropicalis* were on the east coast of North Head peninsula, on Secluded Beach and at the southern end of Goat Bay (fig. 2).

A single breeding group occupied a cove at the southern end of Goat Bay in both 1985–86 and 1986–87; this is one of the "Fur Seal Coves" recorded by Csordas & Ingham (1965) as being frequented by fur seals from 1954–55 onwards. The breeding area is bounded on the northern and western sides by rocky walls, the substrate comprising pebbles interspersed with rocky outcrops 1 m high.

Secluded Beach consists of a pebble beach for most of its 300 m length; it is 20 m wide, with tussock slopes on the western (inland) side and rocks 1 m high in the intertidal zone on the eastern (seaward) side. The major breeding site, in terms of pup production in 1985–86 and 1986–87, was at the southern end beyond the pebble beach, and will be referred to here as South End. It is relatively flat and is bounded to the east by a rocky wall 3 m high and to the west by steep tussock slopes. The main access route to the sea is a gully to the southeast containing rounded rocks 0.2 m high; access to the north, over boulders 1 m high, was used by some cows but rarely by bulls.

In 1986–87, four smaller breeding groups (referred to here as, from south to north, South Beach, Pisa, Central and North End) were formed on Secluded Beach. South Beach was in a U-shaped cranny 2 m across, among rocks, with access to the sea over boulders 2 m high. Pisa was on the pebble beach, flanked on the south by a rock stack and extending to the water's edge. Central was also on the pebble beach and extended into intertidal rocks 1 m high. It was the least clearly defined territory, was frequently occupied by southern elephant seals (*Mirounga leonina*), and was the first territory to disperse. North End was at the northern end of Secluded Beach at the lower edge of tussock slopes, with access to the sea over a pebble beach and through the rocky intertidal zone. In 1985–86, three of these four sites (Pisa, Central and North End) were used. Juveniles belonging to the two breeding species came ashore on Secluded Beach, specially on the tussock slopes and pebble beach near its southern end, and near the breeding territory in Goat Bay.

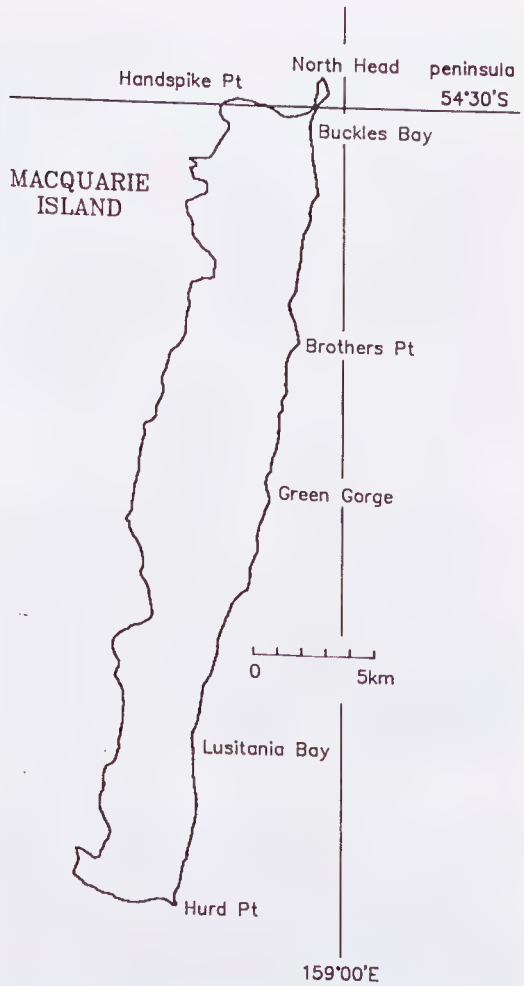

FIG. 3 — Map of Macquarie Island, showing localities where searches for fur seals were conducted.

On North Head peninsula, areas where *A. forsteri* hauled out contained larger rocks than areas preferred by *A. gazella* and *A. tropicalis*. In the terminology of Bester (1982) for habitat of *A. tropicalis* on Gough Island, *A. forsteri* prefers Jumbled Rocky Beaches, and the two breeding species prefer Intermediate Beaches (which have an irregular profile) and Exposed Boulder Beaches (which are more open).

Searches were made for fur seal pups at localities beyond North Head peninsula (fig. 3). In 1985–86, searches were made at Handspike Point (12 January), between Buckles Bay and Green Gorge (10 February and 12 March), between Lusitania Bay and Hurd Point (11 February), and at Hurd Point (27 February). In 1986–87 searches

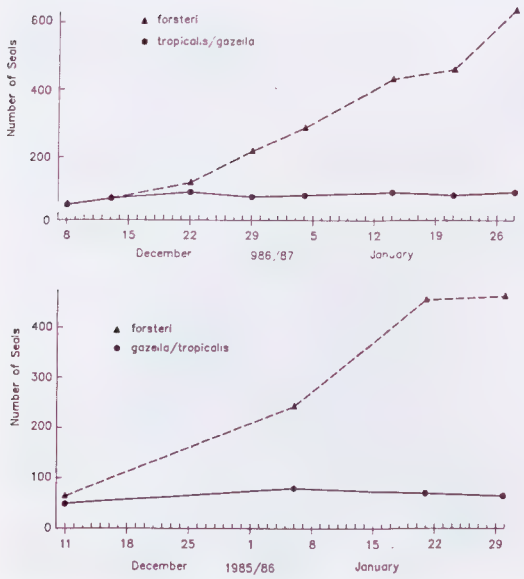

*FIG. 4 — Counts of fur seals (*A. forsteri, A. gazella *and* A. tropicalis*) on North Head peninsula, Macquarie Island, in the summers of (A) 1986–87 and (B) 1985–86.*

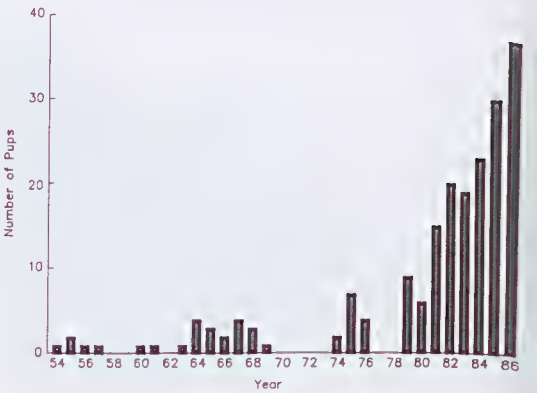

*FIG. 5 — Numbers of fur seal pups (*A. gazella *and* A. tropicalis*) recorded each summer on North Head peninsula, Macquarie Island. No attempt was made to record pup numbers in some years. "Year" refers to the end of a calendar year, since most pups are born in December.*

were made at Handspike Point (15 December and 22 January), between Buckles Bay and Brothers Point (30 December, 2 January and 7 January), between Lusitania Bay and Hurd Point (20 January), and at Hurd Point (9 January). Small numbers of fur seals were seen at Handspike Point, Hurd Point and several sites on the east coast. Most were *A. forsteri*; no black pups, or adults of *A. gazella* or *A. tropicalis* were seen.

COUNTS ON NORTH HEAD PENINSULA DURING SUMMER

In the weekly counts around North Head peninsula, two groups of fur seals were distinguished: the two breeding species in one group and *A. forsteri* in the other. In 1986–87, the number of animals in each group was similar during early and mid-December (fig. 4A), being 50 to 70 animals. Subsequently, numbers of *A. forsteri* increased more rapidly than those of the other two species. In 1986–87, the latter group increased to 100 and then levelled off as territorial structures broke down and cows went to sea to feed. By the end of January, there were 660 *A. forsteri* ashore, while the other two species together numbered only 105.

Fewer data for 1985–86 (fig. 4B) showed similar trends, with slightly lower numbers for each species. This is partly explained by less of the *A. forsteri* habitat being included in the census in 1985–86. Furthermore, it is likely that the *A. gazella*/*A. tropicalis* group was undercounted in 1985–86, as *A. gazella* bulls were not recognised; it seems probable that small numbers of these were present (as in 1986–87) but were counted with *A. forsteri* bulls. Similar results were obtained in 1982–83 from less detailed counts (Shaughnessy & Fletcher 1987, fig. 5).

Counts of fur seals on North Head peninsula are maximal in the period mid-February to early April (Csordas & Ingham 1965). Therefore, the population census is taken in this period in most years. In March 1982, most (98%) of the animals were recorded as *A. forsteri* in the annual census (Shaughnessy & Fletcher 1987).

PUPS AND THE PUPPING SEASON

Numbers of pups recorded on North Head peninsula since 1954–55 show a gradual increase which has been most marked in the 1980's (fig. 5). These counts were made by many different observers and are of varying reliability. Numbers for 1985–86 and 1986–87 (30 and 37 pups respectively) exceed those of previous years.

Counts of pups made on visits to Secluded Beach in 1986–87 are illustrated in figure 6. Towards

the end of January, pup numbers here were swelled by pups that moved from Goat Bay.

Fourteen pups had been born when the study began on 7 December; the last pup was born on 24 December. From simplified probit analysis (Caughley 1980), the median date of birth is calculated as 10 December with standard deviation 8.6 days. In 1985–86, 18 of the 30 pups born (60%) were recorded at the time of the first visit on 11 December, suggesting that the median date of birth was similar to that for 1986–87. Shaughnessy & Fletcher (1987) deduced, from less precise records kept by a variety of observers over 12 seasons, that the pupping season at Macquarie Island extended from late November to mid-December.

Of the 37 pups born on North Head peninsula in 1986–87, 17 were male and 20 were female. This observed ratio of male to female does not differ significantly from a 1:1 sex ratio. Eight of the 37 pups were identified as *A. tropicalis* and 23 as *A. gazella*. The remaining six pups showed characteristics of both species.

Seven of the pups born in 1986–87 were weighed within 24 hours of birth. The average weight of five females was 4.12 kg, with standard deviation of the mean 0.16 kg. For two males, the average weight was 4.15 kg.

Two of the 37 pups had died by the time of our departure in late January 1987. One of these was dead with umbilical cord still attached when first seen on 9 December; a cow was guarding it closely. The other was found drowned under rocks on 4 January. Another three pups were found dead in March and April. The pup mortality rate is therefore 5.4% to the end of January and 13.5% to the end of April.

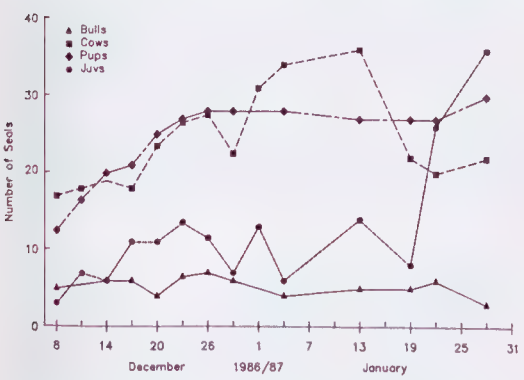

*FIG. 6 — Changes in numbers of breeding fur seals (*A. gazella *and* A. tropicalis*) in four age and sex classes, at Secluded Beach, Macquarie Island, during the 1986–87 summer. Counts in December have been averaged over three-day periods.*

The presence or absence of an umbilical cord on a newly discovered pup can provide useful information about its age, if it is known how long the cord is normally retained. Four pups were seen within 24 hours of birth, and so were of known age; for each of these, the umbilical cord was still attached after two days and had detached by the fourth day. Another five pups retained the umbilical cord for at least two days. Thus we deduce that umbilical cords of fur seal pups at Macquarie Island became detached between two and four days after birth.

COMPOSITION OF BREEDING GROUPS IN 1986–87

In 1986–87, 37 pups were born in six groups, five of which had already established when the study began. Eight pups were born in Goat Bay in a single territory. At Secluded Beach, there were five territories in which the following numbers of pups were born: 1, 4, 3, 3 and 18. Three of the six territories (8, 3 and 18 pups) were controlled solely by *A. tropicalis* bulls. The territory at Pisa (where three pups were born) was not established until 12 December. It was initially held by an *A. gazella* bull which was replaced nine days later by the *A. tropicalis* bull from the adjacent territory (Central). The Pisa group expanded in January, when several pups and their mothers moved there from other groups. The Central group (four pups) was initially held by an *A. tropicalis* bull, and then by each of several *A. gazella* bulls. An *A. gazella* bull (or bulls) was with the sixth group (one pup and its mother) on several occasions. From this account, which is summarised in table 1, it is apparent that most males holding territories were *A. tropicalis*.

That *A. tropicalis* bulls were in charge of more adult females and pups than were *A. gazella* bulls is further illustrated by the average number of bulls in charge of territories and the number of cows per bull on nine occasions between 7 December and 4 January (table 2).

The number of bulls ashore on North Head peninsula remained fairly constant during December and January in the 1986–87 season (fig. 6). By late December cows had spread out within territories and by early January territory structure was breaking down and territorial bulls were beginning to move away and be replaced by other bulls.

Seven *A. tropicalis* bulls were marked with paint; of these, four held territories and three were challengers. *A. gazella* bulls were more difficult to mark because they were not generally holding

TABLE 1

Species composition of fur seals in breeding territories on North Head peninsula, Macquarie Island, in December 1986 and January 1987*

Location of breeding territory	Adult males**		Pups**		
	Bulls	Challengers	A.g.	A.t.	Unknown
Goat Bay	A.t.	A.t. on 20 Jan	6	2	–
Secluded Beach					
North End	A.g. (various, intermittent)	–	1	–	–
Central	A.t. then A.g. (various)	–	3	–	1
Pisa	A.g. then A.t. from Central	–	–	1	2
South Beach	A.t.	–	2	1	–
South End	A.t.	2 A.t. (intermittent) A.t. bull from South Beach on 2 Jan only	10***	4	3

* Most cows were *A. gazella*; few were *A. tropicalis*.
** A.t. denotes *A. tropicalis*; A.g. denotes *A. gazella*.
*** Plus an *A. gazella* pup that died on 9 December.

territories and therefore could not be approached closely. Four of them were marked, but several more were present. Four marked *A. tropicalis* bulls that held territories remained in charge until the end of December (i.e. for the first 3–4 weeks of the study), whereas individual *A. gazella* bulls held territories for a few days only.

Of antagonistic interactions recorded between males, the territory holder was *A. tropicalis* in 18 of 20 instances (table 3). No territory holders were seen to be displaced, although there was one change of ownership during December. In instances when the species of the challenger was identified, it was *A. gazella* more frequently than *A. tropicalis* (10 of 16 occasions).

No bulls were measured, but *A. tropicalis* bulls appeared to be larger than *A. gazella* bulls, and therefore physically more able to win and hold a territory. *A. gazella* bulls were typically in one of three situations: in charge of a small group of cows and pups, on the edge of the largest territory (frequently in the shallows), or on pebble beaches of Secluded Beach, herding small groups of juveniles.

In 1986–87, no *A. forsteri* were recorded in breeding territories, although they were common on offshore rocks at the northern end of Secluded Beach. The presence of *A. forsteri* in territories after *A. tropicalis* bulls had left them was referred to by Shaughnessy & Fletcher (1987). It is possible that these were *A. gazella* bulls mistaken for *A. forsteri*.

Almost all of the cows in territories were identified as *A. gazella*; only a few *A. tropicalis* cows were seen (three certain).

The number of cows ashore (fig. 6) peaked in late December and again in mid-January. Timing of the former peak is similar to that of *A. gazella* cows at Marion Island (Kerley 1983a); the latter peak probably includes animals without pups (i.e. juveniles and adult females that were without pup this season). At South Georgia, cows of *A. gazella* stay ashore feeding their pups for about nine days post-partum and then move to sea to feed for

TABLE 2

Effectiveness of fur seal bulls of each species on North Head Peninsula, Macquarie Island, in the 1986–87 summer*

	A. tropicalis	*A. gazella*
Number of bulls		
Average	4.1	1.0
Range	4-5	0-2
Number of cows per bull		
Average	6.3	1.8
Range	3.2-9.7	1-3

* Data from nine days between 7 December and 4 January, at approximately three-day intervals.

TABLE 3

Antagonistic interactions between males of *A. tropicalis* (A.t.) and *A. gazella* (A.g.) on North Head peninsula during December 1986

Territory holder	Physical herding		Chase			Visual/aural		
	A.t.	A.g.	A.t.	A.g.	Unidentified male*	A.t.	A.g.	Unidentified male*
A tropicalis	2	–	1	5	1	2	4	3
A. gazella	–	1	1	–	–	–	–	–

* The specific identity could not be determined for some small males.

several days at a time (Doidge *et al.* 1986). A similar behavioural pattern at Macquarie would explain fluctuations of their numbers in December and early January.

Copulation was seen on one occasion only, in 1986–87, on 22 December. This was between an *A. tropicalis* bull and an *A. gazella* cow. The cow had given birth between 12 and 13 December. Thus the mating was about 10 days post-partum. The cow went to sea on the following day for four days. Copulation of fur seals has not been reported previously at Macquarie Island.

The number of juveniles ashore increased markedly in late January (fig. 6). Most were on pebble beaches or in tussocks, away from breeding territories. In 1985–86, a similar increase was observed, continuing through February.

TAG RESIGHTING

One of the *A. gazella* cows tagged in 1986–87 was bearing a yellow plastic tag marked "44". This indicated that she had been one of five pups tagged at Secluded Beach in February 1976 and was 11 years old in 1986–87. She was seen frequently with her pup at Secluded Beach during the summer. This is the strongest evidence yet available of a fur seal born at Macquarie Island returning to breed there. There have been several sightings of the 1976 tags in recent years (table 4), but this is the first occasion that one has been positively identified.

RELATIONSHIPS WITH ELEPHANT SEALS

Elephant seals also haul out at Goat Bay and Secluded Beach. During December and January (the fur seals' breeding season), elephant seals are ashore resting and/or moulting. Most are young animals, but subadult males and mature females in their fourth year haul out to moult by mid-January (Ling 1965).

No elephant seals were seen in the fur seals' breeding area in Goat Bay in the 1985–86 or 1986–87 summers. At Secluded Beach, small numbers were frequently within breeding territories

TABLE 4

Sightings of yellow plastic tags* on fur seals on North Head peninsula, Macquarie Island, since 1979–80

Date	Age (years)	Location	Comments/source
23 Dec 1979	4	Secluded Beach	Shaughnessy & Fletcher (1987)
2 Dec 1983	8	Goat Bay	Cow; pup not visible, but cow behaved as if she had a pup (G. Copson, pers. comm.)
2 Jan 1984	8	Goat Bay	as above
16 Dec 1985	10	Goat Bay	Cow; not sighted on subsequent visits
7 Dec 1986	11	Goat Bay	as above
Dec 86 (several occasions)	11	Secluded Beach	Cow with pup, seen frequently. Tag number 44, retagged R foreflipper 0002

* These tags were applied to five pups in February 1976.

of the fur seals, especially at the territory known as Central. For example, on 10 December 1986 that territory included four juvenile elephant seals (aged three months), as well as four fur seal cows and two pups. Fur seals were usually sufficiently attentive and nimble to climb over recumbent elephant seals or to dodge moving ones.

Two young elephant seals remained in the large fur seal territory at the southern end of Secluded Beach for a week from 14 December 1986. Several pups were observed receiving open-mouthed threats from the elephant seals, which resulted in their being almost engulfed in the elephant seals' capacious mouths.

BARNACLES

Barnacles were seen to be infesting the pelage of several *A. gazella* cows in territories, early in the observation period of 1986–87. A small number collected from the flank of one cow were identified as juvenile *Lepas australis* (T. Cochran, Museum of Victoria, pers. comm.). This species is distributed in the Southern Hemisphere in cold temperate to antarctic waters (Foster 1978). There is a previous record of the species from the vicinity of Macquarie Island (Foster 1978); it has also been found on *A. gazella* at South Georgia (Bonner 1968).

DISCUSSION AND CONCLUSIONS

A. gazella and *A. tropicalis* are sympatric at Macquarie Island, as well as at Possession Island in the Crozet Archipelago (Jouventin *et al.* 1982) and at Marion Island (Condy 1978, Kerley 1983b). At the last two localities, *A. tropicalis* is the more abundant species, contrary to the situation at Macquarie Island.

At Marion Island, most *A. gazella* were separate from groups of *A. tropicalis*, but mixed groups were recorded. Hybridisation was strongly suspected at Marion Island, on the basis of sightings of adult males with external characteristics of both species (Condy 1978, Kerley 1983b). Hybridisation was considered probable at Crozet, because both species were present in some breeding territories (Jouventin *et al.* 1982). At Macquarie Island in 1986–87, the five breeding territories with more than one cow contained adults of both species. Hybridisation is suspected because six of the 37 pups appeared to have characteristics of both species. However, no apparently hybrid adults were seen. As noted previously, the only copulation observed at Macquarie was between an *A. tropicalis* male and an *A. gazella* female.

The question of hybridisation could be clarified by an electrophoretic examination of proteins and enzymes in blood samples from pups. As differences have already been demonstrated in the serum protein transferrin for several species of *Arctocephalus*, including those at Macquarie Island (Shaughnessy 1970, Kerley 1984), hybrids should be detectable by this means.

At Macquarie Island in 1986–87, most territorial bulls were *A. tropicalis* and most cows were *A. gazella*. If *A. gazella* cows in territories were not impregnated in 1986–87, they are less likely to frequent the breeding territories in 1987–88 than in 1986–87. Consequently, in the later season they are more likely to be mated by an *A. gazella* male on the periphery of a territory or on the pebble beaches than during the earlier season, when they were actively herded by *A. tropicalis* males in territories and *A. gazella* males were denied access to them.

This idea could be tested in 1987–88 by searching for cows tagged in 1986–87. If it is correct, a corollary would be that cows should appear in breeding territories in 1987–88 that were not seen there in 1986–87. It would imply, furthermore, that the recruitment rate of the population is very low, and any increase in the population will be slow until some *A. gazella* bulls grow to sufficient size to win and hold territories from *A. tropicalis* bulls.

Fur seal mothers and their pups are particularly susceptible to disturbance soon after birth when the mother–pup bond is being established. Therefore we recommend that, while the population level is low, access to Goat Bay and Secluded Beach be restricted during the pupping season in order to limit disturbance.

A. gazella has been reported previously as breeding in Australian waters at Heard Island (Budd & Downes 1969). This study confirms that, as proposed by Shaughnessy & Fletcher (1987), *A. tropicalis* also breeds on Australian territory.

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REFERENCES

BESTER, M.N., 1982: Distribution, habitat selection and colony types of the Amsterdam Island fur Seal *Arctocephalus tropicalis* at Gough Island. *J. Zool. (Lond.)*, 196: 217–231.

BONNER, W.N., 1968: The fur seal of South Georgia. *Brit. Antarct. Surv. Sci. Rep.*, 56: 1–81.

BONNER, W.N., 1981: Southern fur seals Arctocephalus (Geoffroy Saint-Hilaire and Cuvier, 1826). *In* Ridgway, S.H. & Harrison, R.J. (Eds): *HANDBOOK OF MARINE MAMMALS. VOL.1.* Academic Press, London: 161–208.

BUDD, G.M. & DOWNES, M.C., 1969: Population increase and breeding in the Kerguelen fur seal, *Arctocephalus tropicalis gazella*, at Heard Island. *Mammalia*, 33: 58–67.

CAUGHLEY, G., 1980: *ANALYSIS OF VERTEBRATE POPULATIONS.* Wiley, London.

CONDY, P.R., 1978: Distribution, abundance, and annual cycle of fur seals (*Arctocephalus* spp.) on the Prince Edward Islands. *S. Afr. J. Wildl. Res.*, 8: 159–168.

CRAWLEY, M.C. & WILSON, G.J., 1976: The natural history and behaviour of the New Zealand fur seal (*Arctocephalus forsteri*). *Tuatara*, 22: 1–29.

CSORDAS, S.E. & INGHAM, S.E., 1965: The New Zealand fur seal, *Arctocephalus forsteri* (Lesson) at Macquarie Island. *CSIRO Wildl. Res.*, 10: 83–99.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser A(1): 1–380.

DOIDGE, D.W., McCANN, T.S. & CROXALL, J.P., 1986: Attendance behaviour of Antarctic fur seals. *In* Gentry, R.L. & Kooyman, G.L. (Eds): *FUR SEALS: MATERNAL STRATEGIES ON LAND AND AT SEA.* Princeton University Press, Princeton: 102–114.

FOSTER, B.A., 1978: The marine fauna of New Zealand: barnacles (Cirripedia: Thoracica). *N.Z. Oceanogr. Inst. Mem.*, 69: 5–160.

GWYNN, A.M., 1953: Notes on the fur seals at Macquarie Island and Heard Island. *ANARE Int. Rep.*, 4: 1–16.

JOUVENTIN, P., STAHL, J.C. & WEIMERSKIRCH, H., 1982: La recolonisation des Iles Crozet par les otaries (*Arctocephalus tropicalis* et *A. gazella*). Mammalia, 46: 505–514.

KERLEY, G.I.H., 1983a: Comparison of seasonal haul-out patterns of fur seals *Arctocephalus tropicalis* and *A. gazella* on subantarctic Marion Island. *S. Afr. J. Wildl. Res.*, 13: 71–77.

KERLEY, G.I.H., 1983b: Relative population sizes and trends, and hybridization of fur seals *Arctocephalus tropicalis* and *A. gazella* at the Prince Edward Islands, Southern Ocean. *S. Afr. J. Zool.*, 18: 388–392.

KERLEY, G.I.H., 1984: Relationships between sympatric breeding populations of fur seals (*Arctocephalus* sp.) at the Prince Edward Islands. *S. Afr. J. Sci.*, 80: 28–29.

LING, J.K., 1965: Hair growth and moulting in the southern elephant seal *Mirounga leonina* (Linn.). *In* Lyne, A.G. & Short, B.F. (Eds): *BIOLOGY OF THE SKIN AND HAIR GROWTH.* Angus and Robertson, Sydney: 525–544.

PAULIAN, P., 1964: Contribution a l'etude de l'otarie de l'ile Amsterdam. *Mammalia*, 28, suppl. 1: 3–146.

SHAUGHNESSY, P.D., 1970: Serum protein variation in southern fur seals, *Arctocephalus* spp., in relation to their taxonomy. *Aust. J. Zool.*, 18: 331–343.

SHAUGHNESSY, P.D. & FLETCHER, L., 1987: Fur seals, *Arctocephalus* spp., at Macquarie Island. *NOAA Tech. Rep. NMFS* 51: 177–188.

(accepted 22 January 1988)

PERIODIC IRRUPTIONS OF ITINERANT LEOPARD SEALS WITHIN THE AUSTRALASIAN SECTOR OF THE SOUTHERN OCEAN, 1976–86

by David Rounsevell

(with one table and one text-figure)

ROUNSEVELL, D., 1988 (viii): Periodic irruptions of itinerant leopard seals within the Australasian sector of the Southern Ocean, 1976–86. *Pap. Proc. R. Soc. Tasm.*, 122(1): 189–191. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Lands, Parks and Wildlife, Hobart, Tasmania, Australia 7000.

Juvenile and non-breeding leopard seals (*Hydrurga leptonyx*) annually disperse from antarctic pack-ice to Macquarie Island (54°30′S, 158°57′E) and the Australasian region beyond. They occur in the region from June to December, reaching peak abundance at Macquarie Island in August, just before the maximum area of antarctic pack-ice is attained. The most recent annual counts, from 1976 to 1986, of itinerant leopard seals at Macquarie Island show periodically greater than usual numbers. This is consistent with earlier counts made since 1949, which steadily increase and decline every four or five years; peak years coincide with the highest counts recorded on the coasts of Australia and New Zealand subantarctic islands. At present no satisfactory explanation has been found for these long-term irruptions of non-breeding leopard seals from the antarctic pack-ice into the region.
Key Words: leopard seals, Macquarie Island.

INTRODUCTION

The leopard seal, *Hydrurga leptonyx*, is a solitary animal, frequently seen though nowhere common, which reaches sexual maturity probably between the ages of three and six years old (King 1983). Mature seals normally occur in brash or cake ice within 100 km of the northern limit of the antarctic pack-ice (Gilbert & Erickson 1977). Mainly immature animals, after the austral winter, disperse to subantarctic islands when the annual maximum extent of the pack-ice is reached during September and October (Hofman 1975). Animals up to the length of three-year-olds occur regularly at Macquarie Island (54°30′S, 158°57′E) from June to December, their numbers reaching a peak in August (Rounsevell & Eberhard 1980; unless otherwise attributed, material described or discussed below will be found in this publication).

The Australian National Antarctic Research Expedition (ANARE) Station at Macquarie Island has operated continuously since 1948 and the numbers of leopard seals seen at the island have been recorded for all but two years of operation since. Their annual abundance to 1979 has varied periodically (every four or five years during that time), from peaks of 100 or 200 seals to less than 10 seals in the troughs. In the peak years, the seals are also more numerous at other places in the Australasian region (Rounsevell & Eberhard 1980, Elliott 1982, King 1983).

Non-breeding leopard seals are believed to be driven north annually by interspecific aggression, or food shortage, finding temporary habitat and food in subantarctic and temperate regions. As yet no explanation has been found for the longer-term periodic irruptions of leopard seals in the region.

The present paper reports the occurrence of two further irruptions of leopard seals in the Australasian region between 1980 and 1986. The nature of these irruptions, and how they could be used to interpret long-term changes in the antarctic marine ecosystems, are discussed.

METHODS

Leopard seal counts were done at Macquarie Island for the years 1976–86, in conjunction with tagging which commenced in 1976. Incidental counts done from 1949 to 1975 were obtained from station log books, personal records kept by ANARE expeditioners and literature records, and their nature and reliability have been discussed earlier; no count was done in 1950 or 1958.

Tagging of leopard seals at Macquarie Island since 1976 has improved the reliability of annual counts, as an index of the actual number of seals reaching the island. Tagging method is unchanged but tags currently in use are "Jumbo Rototag" [Registered Trademark] which are smaller and made of less flexible plastic than the "Allflex" [Registered Trademark] tags originally used. The

tagging programme has encouraged better surveillance of beaches by ANARE expeditioners searching for seals to tag, often by night. Resightings of tagged seals are primarily responsible for improving the accuracy of annual counts, particularly in high count years, by eliminating the possibility of counting a tagged seal more than once. Approximately two-thirds of the seals reaching the island are successfully tagged. The probability of any one of the remainder being counted twice is quite low because they are often distinctively scarred, and approximately half of them do not return to the island again that year. This more accurate counting may have produced the lower peak counts in 1982 and 1986 in comparison with peak counts obtained in earlier years.

During the last decade, wildlife authorities in Australia and New Zealand have accumulated anectodal reports of leopard seal sightings from the public. The numbers of leopard seals annually reported from New Zealand subantarctic islands and from Tasmania and Victoria in Australia were not obtained by actively searching for seals, as at Macquarie Island, and therefore may only be taken as a coarse index of the numbers of seals present at the time. Reports from New Zealand subantarctic islands include some sightings from the Auckland Islands but most were made by the meteorological staff stationed at Campbell Island; those from Victoria and Tasmania were made principally by members of the public.

LEOPARD SEAL ABUNDANCE

Table 1 contains annual counts of leopard seals at Macquarie Island and the numbers of leopard seals reported annually from three other localities in the Australasian region from 1976–86. The seals were most abundant at Macquarie Island during August in the years 1977, 1982 and 1986. Pooled sightings of leopard seals from the subantarctic islands of New Zealand, Campbell Island and the Auckland Islands, also show maximum frequencies occurred in August 1977 and 1982, corresponding well with years of high abundance at Macquarie Island, despite the lack of data for 1986. The frequencies of leopard seal sightings reported for Tasmania and Victoria are too low to correspond well with changes in abundance at the subantarctic islands.

Figure 1 contains the complete record of leopard seal abundance at Macquarie Island, compiled from recent counts and earlier counts dating from 1949, to show the periodicity of the data up to 1986. Counts prior to 1976 were compiled using available historical records; in some years of low seal numbers no record or incomplete records were kept by expeditioners. Since 1976, low counts (<50) appear to be generally higher than their pre-1976 counterparts and peak counts appear to be lower than most of the pre-1976 peak counts but this, as noted above, may be due to the increased reliability of counts since 1976 when tagging of leopard seals began at Macquarie Island. The periodicity of the changes in abundance since 1976 is unaffected by count reliability and appears to have retained its earlier character. Every four or five years prior to 1986, leopard seal numbers have peaked at Macquarie Island; the timing of those peaks corresponds with peaks of abundance recorded elsewhere in the Australasian region and the ages (lengths) of seals recently observed are similar to those reported earlier.

CONCLUSION

The most intriguing aspect of the irruption of leopard seals into the Australasian sector of the Southern Ocean is the periodic increase and decrease of abundance every four or five years, a phenomenon not reported from subantarctic islands outside the Australasian sector. The cause of these irruptions is unknown and may be either biotic or abiotic. There is a need to investigate it and to

TABLE 1

The numbers of leopard seals recorded annually at four Australasian localities

Location	Year										
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Macquarie Island	120	227	50	12	30	48	57	3	25	27	175
NZ Subantarctic Islands	3	50	3	0	2	7	23	7	5	4	–
Tasmania	0	2	1	2	5	3	3	2	0	1	7
Victoria	1	10	3	1	2	2	2	1	4	2	1

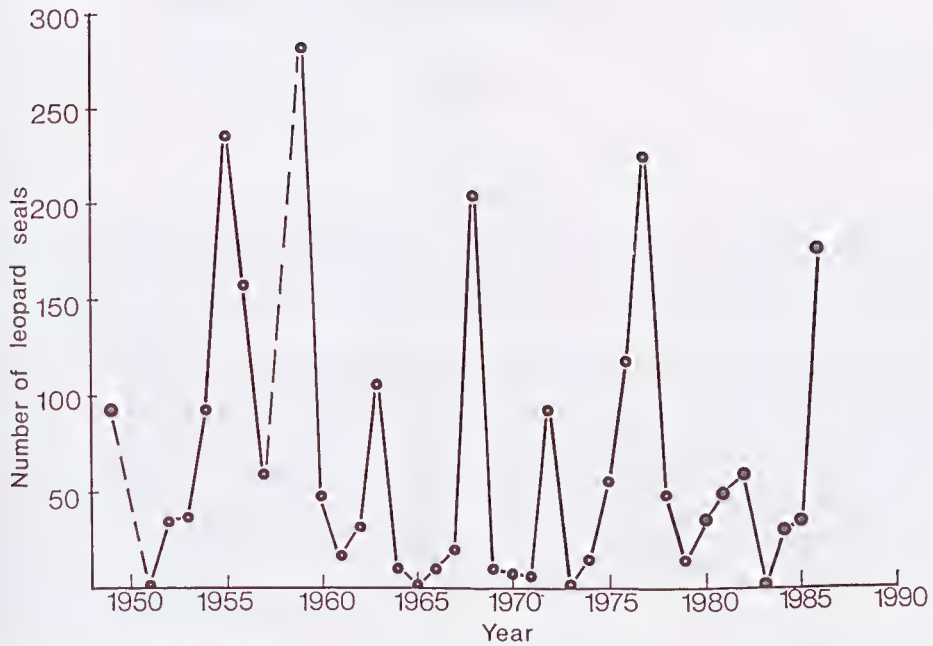

FIG. 1 —Annual abundance of leopard seals at Macquarie Island.

continue monitoring leopard seal abundance in the subantarctic zone. Macquarie Island appears to offer the best site for this in the Australasian sector, as the number of seals recorded there is at least eight times greater than elsewhere and, while the ANARE station is occupied, this provides the cheapest and most effective method of obtaining such information over a long period of time.

To test whether these long-term changes in leopard seal abundance are circum-polar, data are needed from other subantarctic islands, for example, Heard Island, south of the Antarctic Convergence. Although juveniles form a smaller proportion than at Macquarie Island (Brown 1957), making monitoring of the periodic irruptions more difficult, more leopard seals are present annually at Heard Island and it is regularly revisited by breeding seals, making it a useful site for investigating the cause of long-term population changes.

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REFERENCES

BROWN, K.G., 1957: The leopard seal at Heard Island, 1951–54. *ANARE Interim Rep.*, 16: 1–34.

ELLIOTT, M., 1982: Comparison of Macquarie Is. and N.S.W. leopard seal records with notes on their diet. *Thylacinus*, 7(2): 10–15.

GILBERT, J.R. & ERICKSON, A.W., 1977: Distribution and abundance of seals in the pack ice of the Pacific Sector of the Southern Ocean. *In* Llano, G.A. (Ed.): *ADAPTATIONS WITHIN ANTARCTIC ECOSYSTEMS.* Smithsonian Institute, Washington, D.C.: 703–740.

HOFMAN, R.J., 1975: Distribution patterns and population structure of Antarctic seals. Unpublished Ph.D. thesis, University of Minnesota.

KING, J.E., 1983: *SEALS OF THE WORLD.* University of Queensland Press, St Lucia, Queensland.

ROUNSEVELL, D.E. & EBERHARD, I.H., 1980: Leopard seals, *Hydrurga leptonyx* (Pinnipedia), at Macquarie Island from 1949 to 1979. *Aust. Wildl. Res.*, 7: 403–415.

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VIRUSES IN MACQUARIE ISLAND BIRDS

by I.R. Morgan

(with one table)

MORGAN, I.R., 1988 (viii): Viruses in Macquarie Island birds. *Pap. Proc. R. Soc. Tasm.*, 122(1): 193–198. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Agriculture and Rural Affairs, Attwood Veterinary Research Institute, Mickleham Road, Attwood, Victoria, Australia 3047.

Six paramyxoviruses, including a mild strain of Newcastle Disease virus (NDV), were isolated from cloacal swabs collected from 831 penguins, of four species, on Macquarie Island, in the Southern Ocean. Pathogenicity testing showed that these are not harmful to domestic chickens and little blue penguins. Serological testing of 1002 penguins on the island showed that infection with one of the paramyxoviruses was widespread in three of the penguin species. The NDV isolated was similar to a strain present in Australian poultry, prompting speculation on the origin of the infection on Macquarie Island. Serums from 6% of royal penguins had haemagglutination-inhibition antibody to NDV, while the other three species tested showed no evidence of such infection; testing for the presence of avian influenza virus gave negative results. Evidence was also obtained of widespread infection with tick-borne viruses, flavivirus antibodies being detected in some royal, king and rockhopper penguin serums, and viruses being isolated from *Ixodes uriae* ticks found in association with penguin colonies.

Key Words: avian viruses, penguins, Macquarie Island.

INTRODUCTION

Macquarie Island, situated in the Southern Ocean, provides a platform for birds to breed in an area where accessible land is limited. The rich planktonic waters of the circum-polar region provide food for vast numbers of animals of many species. As a result of these two factors, large populations of birds concentrate on the available land during the breeding seasons, providing ample opportunity for diseases to spread between species and between birds of the same species. The island has been continuously occupied by the Australian National Antarctic Research Expedition (ANARE) since 1948, and, in earlier years, domestic poultry were introduced for food. These features provide an ideal environment for the investigation of the presence, or absence, of avian viruses in wild avian populations, particularly where humans have been associated with such populations. This paper summarises investigations carried out by the author (Morgan *et al.* 1978, 1981) and others (Doherty *et al.* 1975, St George *et al.* 1977, 1985).

INVESTIGATIONS

Between 1972 and 1979, *Ixodes uriae* ticks were collected from numerous sites on the island for CSIRO (St George & Kemp 1982) and were examined for the presence of viruses. In addition, 42 royal penguin (*Eudyptes chrysolophus schlegeli*) sera were collected for antibody testing (Doherty *et al.* 1975).

Morgan *et al.* (1978) collected cloacal swabs from 353 royal penguins, 219 king penguins (*Aptenodytes patagonica*), 120 rockhopper penguins (*Eudyptes chrysocome*), 129 gentoo penguins (*Pygoscelis papua*), 39 southern skuas (*Stercorcarius skua lonnbergi*), 50 Macquarie Island shag (*Phalacrocorax albiventer purpurascens*) and 20 juvenile northern giant petrels (*Macronectes halli*). The swabs were examined for the presence of avian viruses by inoculation of chicken embryos.

At the same time, Morgan *et al.* (1978) collected blood samples from 499 royal penguins, 273 king penguins, 120 rockhopper penguins, 110 gentoo penguins and 37 southern skuas. The serum was aspirated from these and used in tests for the presence of viral antibodies.

NEWCASTLE DISEASE

A lentogenic, or relatively non-pathogenic, Newcastle Disease virus (NDV) was isolated from a cloacal swab taken from a royal penguin at Hurd Point by Morgan *et al.* (1978). This virus was subsequently characterised as being serologically identical to the V4 strain of NDV (Simmons 1967) by the NDV Reference Centre, Weybridge, England (D.J. Alexander, pers. comm.). This strain is non-

pathogenic for domestic poultry and has been enzootic in Australian poultry since at least 1960, Hall *et al.* (1967) finding between 15 and 30% of chickens with antibody to it and Eaves *et al.* (1982) 39%. In addition, McKenzie *et al.* (1984) have isolated NDV from ducks, noddies, terns and a black-fronted plover in Western Australia. These were all lentogenic viruses.

Pathogenic strains of NDV have caused lethal infections in penguins in zoological collections (Krause *et al.* 1963) and research collections (Pierson & Pfow 1975). Morgan *et al.* (1985) infected little blue penguins (*Eudyptula minor*) with the V4 strain of NDV without producing disease; the infected penguins excreted virus in faeces for up to 21 days after infection.

In a serological survey of the four penguin species on Macquarie Island, Morgan *et al.* (1978, 1981) found evidence of NDV antibody only in royal penguins, with approximately 6% of 499 birds sampled having serological titres of 1:16 or greater. At most of the sites where birds were sampled, the prevalence of NDV antibody was between 2 and 5%, but at Hurd Point, 15% of birds sampled had antibodies to NDV (table 1). This, together with the isolation of a NDV at this site, suggest that the infection was spreading in this population at the time of sampling, a conclusion re-inforced by work with wild ducks (Spalatin & Hanson 1975) and with little blue penguins (Morgan *et al.* 1985), which showed that detectable NDV antibodies may be short-lived in wild birds.

It is possible that NDV may have been introduced to the island either by domestic poultry from Australia or perhaps by food scraps scavenged by birds such as skuas or giant petrels. The fact that V4 strain of NDV is present in Australia suggests that this may have been the origin of the NDV on Macquarie Island. However, many strains of NDV isolated from wild birds are similar to the V4 strain; thus it is also possible that the virus may have been introduced to Macquarie Island by migratory species.

The finding of evidence of NDV only in royal penguins suggests (1) that either there may be insufficient social contact for the virus to spread to other penguin species or the virus may have low transmissibility, or (2) that royal penguins may come in contact with the virus during their migration from the island.

From these investigations, it is concluded that penguins on Macquarie Island can be infected with NDV. Other work suggests that substantial mortality may result from the introduction of a highly virulent strain of the virus into penguin populations. On the other hand, the presence of a lentogenic strain of NDV in royal penguins may result in the birds infected with this strain having some immunity to infection with a more pathogenic NDV.

AVIAN INFLUENZA VIRUS

Avian Influenza virus (AIV) was not isolated from the 930 cloacal swabs collected from penguins and other species on Macquarie Island by Morgan *et al.* (1978, 1981). In addition, examination of 1039 sera collected at the same time for the presence of AIV antibody showed no evidence of infection with this virus.

Avian Influenza viruses have been isolated from a wide variety of wild birds, mainly migratory species of seabirds or waterbirds (Alexander 1982). Mackenzie *et al.* (1984) isolated 37 AIV from wild birds in Western Australia and have reported the isolation of other AIV from wild birds in Victoria. Fortunately, most of the AIV isolated from wild birds appear to be non-pathogenic. There are only a few strains which cause disease; these include the classical fowl plague virus which caused disease in domestic poultry in Australia in 1976 and again in 1985 (Turner 1976, Barr *et al.* 1986, Forman *et al.* 1986).

The source of the AIV causing disease outbreaks in domestic poultry is usually not determined (Alexander 1982). However, most outbreaks appear to have been associated with close contact between wild birds and domestic poultry, and it is thought that AIV is introduced into a country or region by migrating birds.

If AIV occurred in the bird populations on Macquarie Island, it would probably have been introduced by migratory species.

It appears that some penguin species can be infected by AIV. Morgan *et al.* (1981) reported the detection of antibodies to AIV in adelie penguins (*Pygoscelis adeliae*). The birds with antibody to AIV were in one isolated colony, in which there appeared to be an excess mortality of chicks, but it was not possible to relate the cause of the mortality to AIV.

PARAMYXOVIRUSES

Morgan *et al.* (1978, 1981) isolated five paramyxoviruses in cloacal swabs collected from four royal penguins and a king penguin on Macquarie Island, all from birds sampled at the same site but at different times. There was a gap of

TABLE 1

Serum Haemagglutination-inhibition Antibody to Newcastle Disease Virus, Paramyxovirus PMV-1, and the Flavivirus — Murray Valley Encephalitis Virus in Penguins on Macquarie Island

Species	Location	Number with antibody to:		
		NDV	PMV-1	MVE
Royal penguin	Nuggets	5/199	5/199	6/151
	Sandy Bay	3/89	5/89	2/79
	Hurd Point	14/93	11/93	0/68
	Bauer Bay	5/30	4/30	0/19
	Flat Creek	3/59	4/59	1/38
	Red River	1/29	0/29	0/29
King penguin	Nuggets	0/33	0/33	0/14
	Sandy Bay	0/60	0/60	7/59
	Lusitania Bay	0/180	2/180	0/145
Rockhopper penguin	Sandy Bay	0/20	0/20	1/13
	Lusitania Bay	0/60	3/60	1/49
	Caroline Cove	0/40	0/40	5/39
Gentoo penguin	Base area	0/60	0/60	0/44
	Bauer Bay	0/10	0/10	0/10
	Sandy Bay	0/10	0/10	0/7
	Middle Beach	0/30	0/30	0/24
Skua	various	0/37	–	1/30

approximately three months between the collection of the first infected swab and the last. The isolates were subsequently categorised (at the NDV Reference Laboratory, Weybridge, England) into two distinct serological groups (not yet completely categorised) (D.J. Alexander, pers. comm.). A large number of paramyxoviruses have been isolated from wild and domestic birds; these have been categorised into nine types (Alexander 1980). The viruses isolated from penguins on Macquarie Island appear to be a new group. Similar viruses have been isolated from adelie penguins at McMurdo Sound (F.J. Austin, pers. comm.), Casey (Morgan *et al.* 1981) and Davis (Morgan & Westbury, in press) research stations in the antarctic.

Inoculation of the Macquarie Island penguin paramyxoviruses into young and adult domestic chickens has shown that they do not produce disease (D.J. Alexander, pers. comm.). Similarly, inoculation of one of the viruses into little blue penguins failed to produce disease (Morgan *et al.* 1985). In general, infection with paramyxoviruses does not produce disease. However, some may interact synergistically with other infections to produce a more severe disease (Lang *et al.* 1975).

All penguin species on Macquarie Island, except gentoo, showed evidence of infection with one of the paramyxoviruses isolated from a royal penguin. Antibodies to this virus were found in 5.8% of royal penguins, 2.5% of rockhopper penguins and 0.7% of king penguins (table 1). Antibodies to the same virus have been found in 7% of little blue penguins tested on the Victorian coast (Morgan *et al.* 1985).

The widespread distribution of paramyxoviruses in penguin populations from three distinct geographical regions suggests that these viruses are part of the normal virological experience of penguins. The paramyxoviruses isolated from penguins on Macquarie Island share some of the genetic and serological characteristics of NDV (D.J. Alexander, pers. comm.) and it is possible that as a result they may provide some immunity to infection with this virus. Alexander *et al.* (1979) have shown that some paramyxoviruses may protect birds from challenge with virulent NDV.

TICKBORNE VIRUSES

Doherty *et al.* (1975) isolated two viruses from *Ixodes uriae* ticks collected from penguin colonies on Macquarie Island. One, Nugget virus, was characterised as belonging to the Kemerovo serogroup and the other, Taggert virus, belonged to the Sakhalin serogroup. Viruses from both these groups had previously been isolated from *I. uriae* collected in several areas of the Northern Hemisphere (Main *et al.* 1973, Lvov *et al.* 1973, 1974, Thomas et al. 1973, Yuncker 1975).

St George & Kemp (1982) reported the isolation of flaviviruses from *I. uriae* collected from penguin colonies on Macquarie Island. Subsequently one of the viruses was identified as Samaurez Reef (SAZ) virus (St George, pers. comm.). This virus was previously isolated from *Ornithodorus capensis* collected on coral cays off the east coast of Queensland and from *Ixodes eudyptidis* collected in northern Tasmania (St George *et al.* 1977).

Morgan *et al.* (1978) isolated 23 viruses from I. uriae collected at five penguin colonies on Macquarie Island. Further characterisation of these viruses has been delayed by a backlog at the reference laboratory.

The SAZ virus and two of the viruses isolated by Morgan *et al.* (1978) were inoculated into little blue penguins by Morgan *et al.* (1985). Birds inoculated with SAZ virus died 9 to 13 days later, indicating that these viruses may be lethal for penguins. A similar outcome resulted from inoculation of another virus designated AUST-MI-411.

Antibody to Nugget virus was found in 14 of 42 royal penguin sera tested and antibody to Taggert virus in 4 of 31 of the same sera by Doherty *et al.* (1975). St George *et al.* (1977) found no evidence of infection with the SAZ virus in royal penguin sera. Morgan *et al.* (1978) found flavivirus antibodies in 2.3% of 384 royal penguin sera, 3.2% of 218 king penguin sera, 7% of rockhopper penguin sera and 1% of skua sera (table 1). Antibodies to flavivirus were not found in the 85 gentoo penguin sera tested. The antibody titres ranged from 1:20 to 1:2560, indicating a strong immunity to infection with the flavivirus.

The finding of viruses in *Ixodes uriae* ticks on Macquarie Island is interesting because *I. uriae* also occurs in the subarctic regions of the Northern Hemisphere and similar viruses have been recovered from ticks collected from subarctic habitats. It is possible that migratory birds may have brought either ticks or the viruses into the Southern Hemisphere, or that the Southern Hemisphere was a source of ticks or virus for the Northern Hemisphere.

SUMMARY

When birds gather in large concentrations, such as in breeding colonies, there are increased chances of significant mortalities. Factors such as predation, lack of food, inclement weather and disease can exert a greater effect on such groups than on species which are less colonial in breeding and roosting. Once introduced into large populations, diseases may spread rapidly, not only due to the close proximity of individuals but also because of the lowered immunity due to the social and nutritional stresses of the breeding period. Infection by avian viruses, particularly those which may cause disease in domestic poultry, may be a part of the natural ecology of some wild bird populations and may have minimal impact on them; the paramyxoviruses isolated in the studies reported here appear to fall into this category. Some viruses, not endemic, may cause widespread disease when introduced into a population, while others may become endemic.

In the early years of ANARE, Macquarie Island had a resident population of domestic poultry, including ducks and geese, which could have created the potential for the spread of avian viruses to the indigenous avian populations. In addition, virus-infected food wastes may have transmitted infections to scavenger species such as skuas. The isolation of a Newcastle Disease virus, similar to that present in Australian domestic poultry, suggests that humans may have been the agent for introducing this virus to the island.

Macquarie Island has large populations of four species of penguins occupying a variety of nesting sites. The four species differ in the size, concentration and, occasionally, location of their breeding colonies. In addition, two of the species migrate from the island for lengthy periods, while the other two are resident all year. The studies reported here show that these penguins have been infected with a number of viruses, probably from a number of sources.

Large populations of the tick *Ixodes (Ceratixodes) uriae* are associated with the seabird colonies on the island, providing opportunity for the spread of arthropod-borne viruses between birds. The recovery of a large number of virus isolates from ticks on Macquarie Island, and the associated serology, show that these viruses are a part of the ecology of penguins on the island. Similar viruses are found in both birds and ticks in

subarctic regions, prompting speculation on their origin. It is possible that there is interchange of viral genetic material between the subarctic and subantarctic regions by migrating birds.

Because of its isolated geographical position and its varying faunal and human occupation, Macquarie Island provides an ideal setting in which to study the ecology of virus diseases in wild birds.

REFERENCES

ALEXANDER, D.J., 1980: Avian paramyxoviruses. *Vet. Bull.*, 50: 737–752.

ALEXANDER, D.J., 1982: Avian influenza — recent developments. *Vet. Bull.*, 52: 341–359.

ALEXANDER, D.J., CHETTLE, N.J. & PARSONS, G., 1979: Resistance of chickens to challenge with the virulent Herts strain of Newcastle disease virus induced by prior infection with a serologically distinct avian paramyxovirus. *Res. vet. Sci.*, 26: 198–201.

BARR, D.A., KELLY, A.P., BADMAN, R.T., CAMPEY, A.R., O'ROURKE, M.D., GRIX, D.C. & REECE, R.L., 1986: Avian influenza on a multi-age chicken farm. *Aust. vet. J.*, 63: 195–196.

DOHERTY, R.L., CARLEY, J.G., MURRAY, M.D., MAIN, A.J., KAY, B.H. & DOMROW, R., 1975: Isolation of arboviruses (Kemerovo Group, Sakhalin Group) from *Ixodes uriae* collected at Macquarie Island, Southern Ocean. *Am. J. Trop. Med. Hyg.*, 24: 521–526.

EAVES, F.W., AMIGH, M.J. & GRIMES, T.M., 1982: Survey of Queensland poultry flocks for antibody to Newcastle disease virus. *Aust. vet. J.*, 59: 126–127.

FORMAN, A.J., PARSONSON, I.M. & DOUGHTY, W.J., 1986: The pathogenicity of an avian influenza virus isolated in Victoria. *Aust. vet. J.*, 63: 294–296.

HALL, W.T.K., ROSENFELD, L.E. & SIMMONS, G.C., 1967: Studies on the serological response and the pathogenicity of Queensland isolate of Newcastle disease virus. *Aust. vet. J.*, 43: 400–404.

KRAUSE, H., PAULICK, C., HUCHZERMEYER, F. & GYLSTORFF, I., 1963: Newcastle disease in a King penguin. *Dtsch. tierarztl. Wschr.*, 70: 307–309.

LANG, G., GAGNON, A. & HOWEL, J., 1975: The occurrence of paramyxovirus. Yucaipes in Canadian poultry. *Can. vet. J.*, 16: 233–237.

LVOV, D.K., TIMOPHEEVA, A.A., GROMASHEVSKI, V.L., TSYRKIN, Yu.M., SAZONOV, A.A., POGREBENKO, A.G., SIDOROVA, G.A., GOSTINSHCHIKOVA, G.V., KHUTORETSKAYA, N.V., GUSCHA, V.I., FOMINA, K.B., CHERVONSKI, V.I., ARISTOVA, V.A., LEONOVA, G.N., ZHEZMER, V.Yu., SHIBAEV, Yu.V., YUDAKOV, A.G., FILATOV, F.P. & CHUMAKOV, V.M., 1974: The ecology of Sakhalin virus in the north of the far east of the USSR. *J. hyg. epidem. microbiol. immunol.*, 18: 87–95.

LVOV, D.K., TIMOPHEEVA, A.A., GROMASHEVSKI, V.L., TSYRKIN, Yu.M., VESELOVSKAYA, O.V., GOSTINSHCHIKOVA, G.V., KHUTORETSKAYA, N.V., POGREBENKO, A.G., ARISTOVA, V.A., SAZONOV, A.A., CHERVONSKI, V.I., SIDOROVA, G.A., FOMINA, K.B. & ZHEZMER, V.Yu., 1973: "Okhotskiy" virus, a new arbovirus of the Kemerovo group isolated from *Ixodes (Ceratixodes) putus* Pick. Camb. 1878 in the Far East. *Arch. gesamte Virusforsch.*, 41: 160–164.

MACKENZIE, J.S., EDWARDS, E.C., HOLMES, R.M. & HINSHAW, V.S., 1984: Isolation of ortho- and paramyxoviruses from wild birds in Western Australia, and the characterisation of novel influenza viruses. *Aust. J. exp. biol. med. sci.*, 62: 89–99.

MAIN, A.J., DOWNS, W.G., SHOPE, R.E. & WALLIS, R.C., 1976: Avian arboviruses of the Witless Bay Seabird Sanctuary, Newfoundland, Canada. *J. wildl. dis.*, 12: 182–194.

MORGAN, I.R., CAPLE, I.W., WESTBURY, H.A. & CAMPBELL, J., 1978: Disease investigations of penguins and elephant seals on Macquarie Island. *Dept of Agriculture, Victoria, Res. Proj. Ser.* No.47.

MORGAN, I.R. & WESTBURY, H.A., in press: Studies of viruses in penguins in the Vestfold Hills. *In* Ferris, J. (Ed.): *HYDROBIOLOGIA AND DEVELOPMENTS IN HYDROBIOLOGY.*

MORGAN, I.R., WESTBURY, H.A. & CAMPBELL, J., 1985: Viral infections of Little Blue penguins (*Eudyptula minor*) along the southern coast of Australia. *J. wildl. dis.*, 21: 193–198.

MORGAN, I.R., WESTBURY, H.A., CAPLE, I.W. & CAMPBELL, J., 1981: A survey of virus infection in sub-antarctic penguins on Macquarie Island, Southern Ocean. *Aust. vet. J.*, 57: 333–335.

PIERSON, G.P. & PFOW, C.J., 1975: Newcastle disease surveillance in the United States. *J. Am. vet. med. Ass.*, 167: 801–803.

SIMMONS, G.C., 1967: The isolation of Newcastle Disease virus in Queensland. *Aust. vet. J.*, 43: 29–30.

SPALATIN, J. & HANSON, R.P., 1975: Epizootiology of Newcastle disease in waterfowl. *Avian dis.*, 19: 573–582.

ST GEORGE, T.D., DOHERTY, R.L., CARLEY, J.G., FILIPPICH, C., BRESCIA, A., CASALS, J., KEMP, D.H. & BROTHERS, N., 1985: The isolation of arboviruses including a new flavivirus and a new bunyavirus from *Ixodes*

(Ceratixodes) uriae (Ixodoidea:Ixodidae) collected at Macquarie Island, Australia, 1975–1979. *Am. J. Trop. Med. Hyg.*, 34: 406–412.

ST GEORGE, T.D. & KEMP, D.H., 1982: Ticks and arboviruses in Australia and its territories. Refresher Course on Veterinary Virology. *The University of Sydney Postgraduate Committee in Veterinary Science. Refresher Course for Veterinarians, Proc.* No. 60.

ST GEORGE, T.D., STANDFAST, H.A., DOHERTY, R.L., CARLEY, J.G., FILLIPICH, C. & CASALS, J., 1977: The isolation of Saumarez Reef virus, a new flavivirus, from bird ticks *Ornithodorus capensis* and *Ixodes eudyptidis* in Australia. *Aust. J. exp. biol. med. sci.*, 55: 493–499.

THOMAS, L.A., CLIFFORD, C.M., YUNKER, C.E., KEIRANS, J.E., PATZER, E.R., MONK, G.E. & EASTON, E.R., 1973: Tickborne viruses in Western North America. I. Viruses isolated from *Ixodes uriae* in coastal Oregon in 1970. *J. med. Ent.*, 10: 165–168.

TURNER, A.J., 1976: The isolation of fowl plague virus in Victoria. *Aust. vet. J.*, 52: 384.

YUNKER, C.E., 1975: Tick-borne viruses associated with sea-birds in North America and related island. *Med. Biol*, 53: 302–311.

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CONCEPTACLE DEVELOPMENT, GAMETE MATURATION AND EMBRYOLOGY OF *DURVILLAEA ANTARCTICA* FROM MACQUARIE ISLAND

by Megan Klemm and Neil Hallam

(with one text-figure and seven plates)

KLEMM, M. & HALLAM, N., 1988 (viii): Conceptacle development, gamete maturation and embryology of *Durvillaea antarctica* from Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 199–210, 7 pl. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Botany Department, Monash University, Clayton, Victoria, Australia 3168.

Studies on *Durvillaea antarctica* on Macquarie Island, in the subantarctic, were conducted throughout 1984 and in the summers of 1983 and 1985. Thereafter the annual sequence of conceptacle initiation, development, maturation and senescence was examined, using light and electron microscopy. *Durvillaea antarctica* on Macquarie Island releases mature ova and spermatozooids from February to August, with early stages of conceptacle development being observed during November, December and January, and senescent conceptacles from September to December.

Both intertidal and subtidal forms of *Durvillaea antarctica* are found on Macquarie Island, the subtidal form lacking air cavities. In the light of mating experiments which resulted in successful cross-fertilisation, the two forms are considered to be conspecific.

Key Words: *Durvillaea antarctica*, gamete production, Macquarie Island.

INTRODUCTION

The genus *Durvillaea* has a circumpolar distribution in the Southern Hemisphere (Hay 1979). *Durvillaea antarctica* (Chamisso) Hariot, the species found on Macquarie Island, is also found on the coasts of southern New Zealand, South America and other circumpolar islands, for example, Heard Island and the Falkland Islands.

Two forms of *Durvillaea antarctica* are found on Macquarie Island. The plants restricted to the intertidal zone have an expanded, air-filled medulla (plate 1A) allowing the fronds to float on the surface; those plants which remain submerged at all times have a compressed medulla (plate 1B). These differences are not always distinct, a number of plants having areas of both inflated and compressed medullary tissue. Hay (1979) reports similar morphological variation in *Durvillaea* populations on Chatham Island and Antipodes Island; he has created a separate species, *D. chathamensis* Hay, for the Chatham Island form and suggested the possibility of a separate species for the Antipodes Island form. The present study sought to determine whether the two forms on Macquarie Island differed enough from each other to require taxonomic separation

Both forms reproduce in the same way, with separate male and female plants producing large numbers of gametes. Many of the large, brown algae reproduce seasonally. *D. potatorum*, the southern Australian representative of the genus, releases gametes during winter and early spring (Clayton *et al.* 1987). Initial observations during the summer of 1983–84 indicated that *Durvillaea antarctica* on Macquarie Island became fertile earlier in the year. Monthly samples processed on our behalf during 1984 by Dr Andrew Climie (Medical Officer, Macquarie Island) allowed the seasonal changes in gamete initiation and maturation to be examined in detail throughout the year.

MATERIALS AND METHODS

Light and Transmission Electron Microscopy

Small (2 mm^3) pieces of *Durvillaea* thallus were fixed for two hours in a modified Karnovsky fixative containing 4% glutaraldehyde, 4% paraformaldehyde and 1% caffeine in 0.05 M sodium cacodylate buffered seawater at pH 7.2. Tissue was given 3 × 20 minute rinses in 0.05 M sodium cacodylate buffered seawater containing 1% caffeine, post-fixed in 1% Os O_4 in buffer (without caffeine) for one hour, and dehydrated through an acetone series (5, 10, 15, 20, 30, 40, 50, 60, 70% for 15 minutes each). Tissue was retained in 70% acetone for transport to Australia. At Monash

University, tissue was further dehydrated (80, 90, 95 and 3 × 100% changes of acetone for 15 minutes each) and infiltrated with low viscosity resin using the peristaltic pump method (Hallam & Luff 1988). Once into 100% resin, the resin was changed twice daily for five days before the tissue was polymerised in fresh resin at 60°C.

For light microscopy, sections 0.5–2 μm thick were cut on a glass knife using a Reichert OMU3 or Ultracut microtome, and stained with Toluidine Blue at pH 9.

For transmission electron microscopy, silver or silver-gold sections were cut on a diamond knife, using a Reichert OMU3 or Ultracut E ultramicrotome, and collected on formvar-coated copper slot grids or uncoated copper mesh grids. Grids were stained for two minutes in Uranyl acetate and eight minutes in Reynold's Lead citrate (Reynolds 1963), and viewed with a JEOL 200CX transmission electron microscope at 80 kV.

Scanning Electron Microscopy

Pieces of *Durvillaea* thallus (up to 1 cm^3) were fixed and dehydrated as above. Specimens in 100% acetone were critical-point dried, mounted on stubs and sputter-coated with platinum, before viewing in a Hitachi 570 or ISI 60 scanning electron microscope.

Establishment and Maintenance of Cultures

To obtain gamete release, pieces of thallus (10 cm^2) were rinsed in seawater and wiped with paper towel to remove previously discharged gametes. Thallus pieces were left exposed to the air for 10–15 minutes, during which time gametes began to exude on the surface. Tissue was then shaken in large containers or plastic bags with cold, filtered seawater to stimulate gamete release.

To establish the cultures, male and female gametes from each "form" were collected. Ten replicates of each possible cross (intertidal female x intertidal male, intertidal female x subtidal male, subtidal female x subtidal male, subtidal female x intertidal male) were established on prepolymerised discs of Spurr's resin contained in individual 5 cm petri dishes. These were placed outside (2–5°C) at Macquarie Island, in an area protected from elephant seals where they received natural light. Cultures were maintained for six days, with daily seawater changes. After one week's growth the discs were screwed on rocks in the intertidal area, being retrieved at weekly intervals for fixation.

Growth Rate of Germlings

For six days after fertilisation, daily samples (minimum 20) were removed from each culture of each cross and measured (total length, maximum width in μm) under 400x magnification. The mean and standard deviation for each sample was calculated. It was planned to continue these measurements weekly in retrieved samples, but few germlings remained on the discs, all of which were required for microscopy.

RESULTS

Conceptacle Initiation

Gametes of *Durvillaea antarctica* develop in conceptacles which are flask-shaped at maturity with a small opening to the surface, the ostiole. Conceptacles are initiated in the cortex, slightly below the plant surface. Cell walls in the region of conceptacle initiation begin to degrade (plate 2A) allowing a cavity to form (plate 2B). This cavity is filled with mucilagenous materials, indicated by histochemical staining to be a sulphated polysaccharide. As the cavity enlarges, the cells lining it become compressed (plate 2C).

Short filamentous hairs (plate 2D) develop from some of the cells lining the conceptacle and extend into the central cavity. Either oogonia (in female plants) or anteridia (in male plants) develop on the filaments. In Durvillaea antarctica on Macquarie Island, conceptacles were initiated and immature gametangia were first observed during December and January.

GAMETE MATURATION

In female plants, immature oogonia consist of a stalk cell and an oogonial initial, resulting from a transverse division in an outgrowth from a conceptacle lining cell (plate 3A). The cytoplasm is dense, containing numerous chloroplasts. The young oogonium is surrounded by a single wall layer. The nucleus undergoes meiosis and a subsequent mitosis to produce eight nuclei, four of which degenerate. Walls develop which separate the four remaining nuclei, producing an oogonium containing four ova (plate 3B).

As oogonia mature, the cytoplasm remains dense. Ova have a central nucleus surrounded by chloroplasts, lipid droplets and phenolic deposits (plate 3C), mitochondria and dictyosomes (plate 3D). Mature female conceptacles contain large numbers of oogonia (plate 3E).

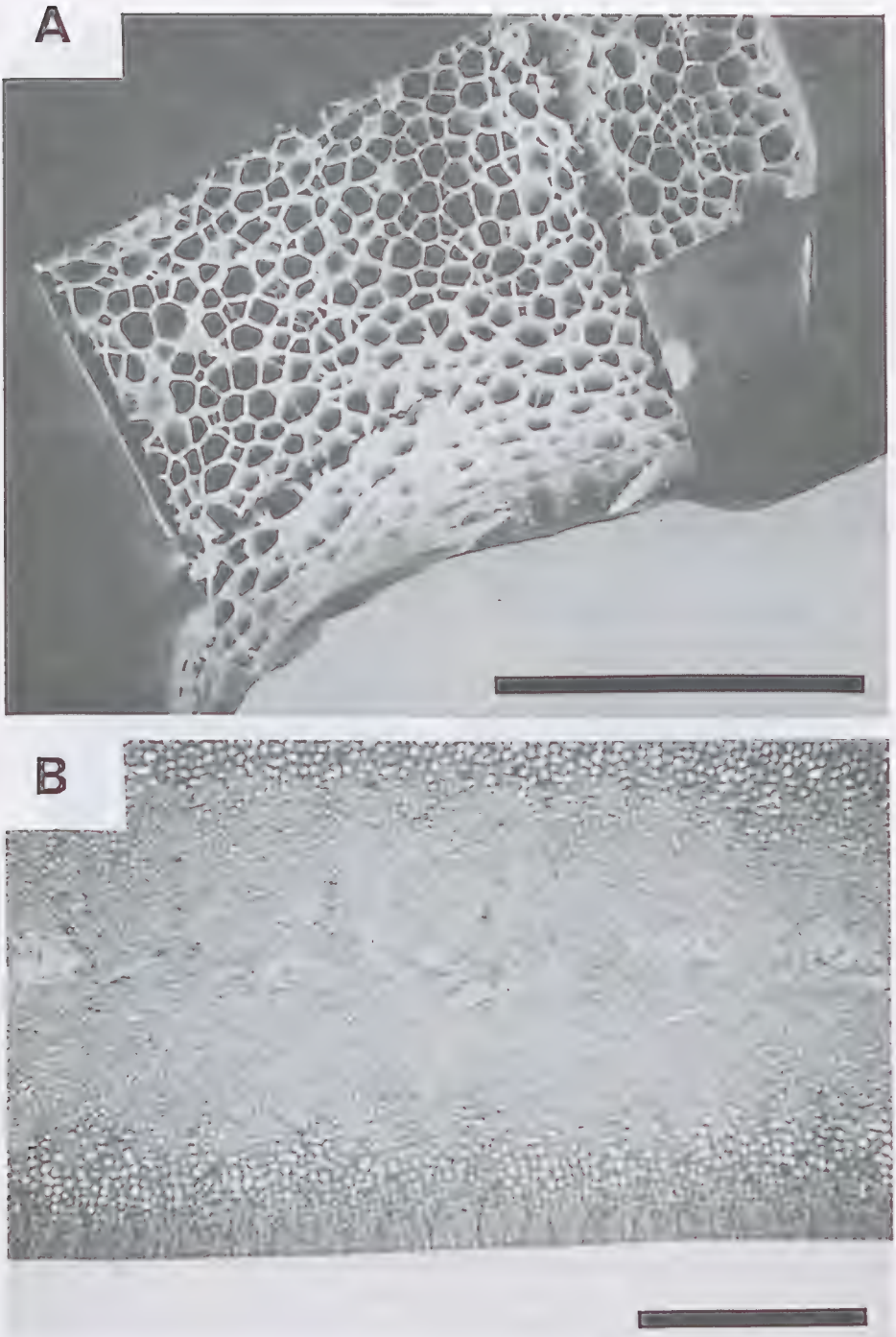

PLATE 1

A: Inflated medulla of D. antarctica *from the intertidal area. Bar = 50 mm. B: Section showing the compressed medulla of* D. antarctica *from the subtidal area. Bar = 1 mm.*

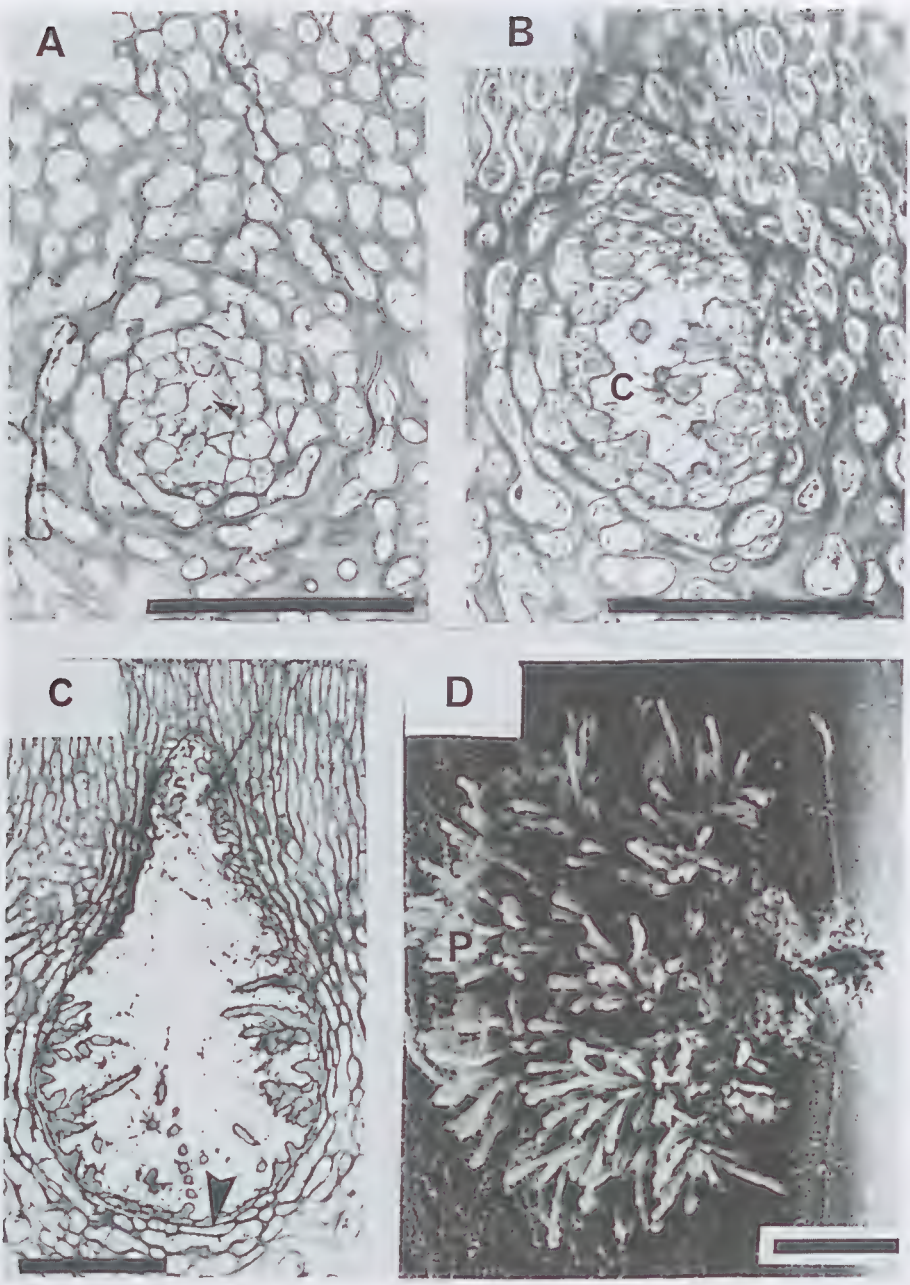

PLATE 2

A: Breakdown of cell walls (arrowed) in the region of conceptacle initiation in D. antarctica. *Bar = 100 μm.*
B: Cavity formation (C) in the early stage of conceptacle initiation in D. antarctica. *Bar = 100 μm.*
C: Compressed cells (arrowed) lining a developing conceptacle of D. antarctica. *Bar = 200 μm.*
D: Scanning electrom micrograph showing filamentous hairs (P) within a conceptacle of D. antarctica. *Bar = 200 μm.*

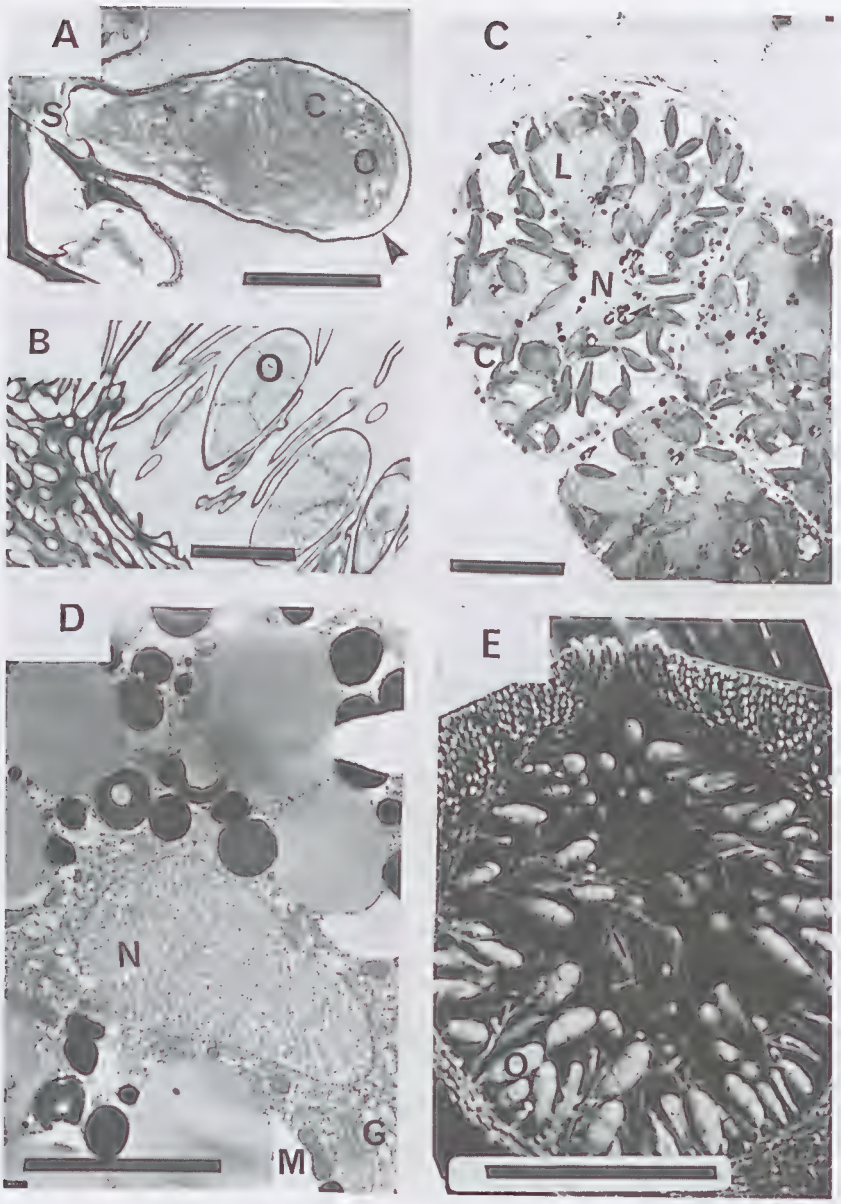

PLATE 3

A: Transmission electron micrograph of an oogonial initial (O) and stalk cell (S) showing chloroplasts (C) and single, surrounding cell wall layer (arrowed). Bar = 10 μm.
B: Oogonium (O) which has undergone cleavage. Bar = 10 μm.
C: Transmission electronmicrograph of an oogonium showing the nucleus (N), chloroplasts (C), lipid droplets (L) and phenolic deposits (arrowed). Bar = 10 μm.
D: Transmission electron micrograph of an egg nucleus (N) and surrounding cytoplasm, including Golgi bodies (G) and mitochondria (M). Bar = 5 μm.
E: Scanning electron micrograph showing mature ooginia (O) within a conceptacle. Bar = 100 μm.

In male plants the single nucleus of the antheridial initial undergoes meiosis to produce a young antheridium containing four nuclei surrounded by dense cytoplasm (plate 4A). Subsequent mitoses result in the formation of 64 sperm or antherozooids within each antheridium. The antherozooids become delimited, with each nucleus associated with mitochondrial profiles and a Golgi dictyosome (plate 4B). When the sperm are almost mature, two flagella are formed, inserted close to the nucleus (plate 4B). These are responsible for sperm motility following release. Large numbers of antheridia develop in male conceptacles (plate 4C).

Sections of monthly samples from Macquarie Island have shown that mature gametes are present in the conceptacles from February to August. Gametes are continually being initiated during this period, i.e. gametes are in different stages of maturity. Studies conducted in 1985–86 indicate a gamete maturation period of 4–6 weeks from initiation. Gametes are released from the conceptacles once every two weeks during the fertile period. Gamete release coincides with the first day of mean low-water spring tides in each fortnight.

DEGENERATING CONCEPTACLES

Sections cut from material collected on Macquarie Island during September, October, November and December show degenerating conceptacles. These conceptacles contain wall material from released gametes, and occasionally aborted gametes (plate 5A). Growth of filaments within the conceptacle block the ostiole (plate 5A) and the conceptacle cavity (plate 5B). Secretion of intercellular matrix material gradually fills the conceptacle cavity (plate 5C), so that ultimately the old conceptacles are difficult to distinguish from surrounding thallus tissue.

The degeneration of conceptacles takes place over a number of years. Sections through thallus show several generations of conceptacles (plate 5D). The degeneration of conceptacles overlaps with production of new conceptacles in *Durvillaea antarctica* on Macquarie Island.

RELEASED GAMETES

Oogonia and antheridia are surrounded by two layers of wall material within the conceptacles. The outer wall layer ruptures, releasing gametes into the conceptacle layer. The gametes, still enclosed in a single layer of wall material, are released through the ostiole. Upon contact with seawater this wall degenerates, releasing gametes surrounded by a cell membrane.

Eggs round up (plate 6A) and, being slightly denser than seawater, sink to the bottom. The eggs contain a central nucleus surrounded by cytoplasmic organelles including mitochondria and Golgi bodies (plate 6B). The convoluted nuclear membrane (plates 6B, 6C) indicates recent penetration by sperm. A large proportion of the egg volume is occupied by vacuoles of various kinds and chloroplasts (plate 6C). The eggs remain healthy for up to six hours if kept cold.

Entire antheridia are released through the ostiole. The flagella of sperm contained within them can be observed beating, and the sperm "swim" away rapidly after antheridial wall breakdown. Fine structure of active sperm remains the same as that described for mature sperm within antheridia. Sperm are attracted to released eggs by the chemical pheromone Hormosirene (Muller *et al.* 1985) secreted by the egg. Sperm remain active for approximate one hour if kept cold (i.e. about 5°C).

EMBRYOLOGY

Fertilisation experiments were performed during the 1986 summer. All possible crosses were successful, i.e. fusion of male and female gametes from the intertidal form resulted in germlings, and fusion of male and female gametes from the subtidal form resulted in germlings. In addition, female gametes of the intertidal form were successfully fertilised by sperm from the subtidal form and vice versa. Growth-rate measurements from each cross are presented in figure 1. The germlings which showed similar, rapid growth rates were those resulting from eggs of both forms which had been fertilised by sperm from intertidal plants. The germlings which showed a slower growth rate resulted from eggs of both forms fertilised by sperm from subtidal plants.

Early development in all crosses was identical. Fertilised zygotes sink rapidly to the bottom. Within 1–2 hours, an adhesive mucilage has been secreted which firmly adheres the germling to the substratum. Polarisation occurs within 15 hours of fertilisation. The vectors known to influence polarity include the direction of incident light, pH of the surrounding medium and the point of sperm entry. Soon after, an unequal division occurs (plate 7A), dividing the germling into a large upper cell and a smaller, lower cell. The lower cell is the rhizoid. Further divisions of the upper cell, and elongation of the lower cell (plate 7B) result in a typical 2–3-day-old, club-shaped germling. Later in development the thallus flattens (plate 7C) and

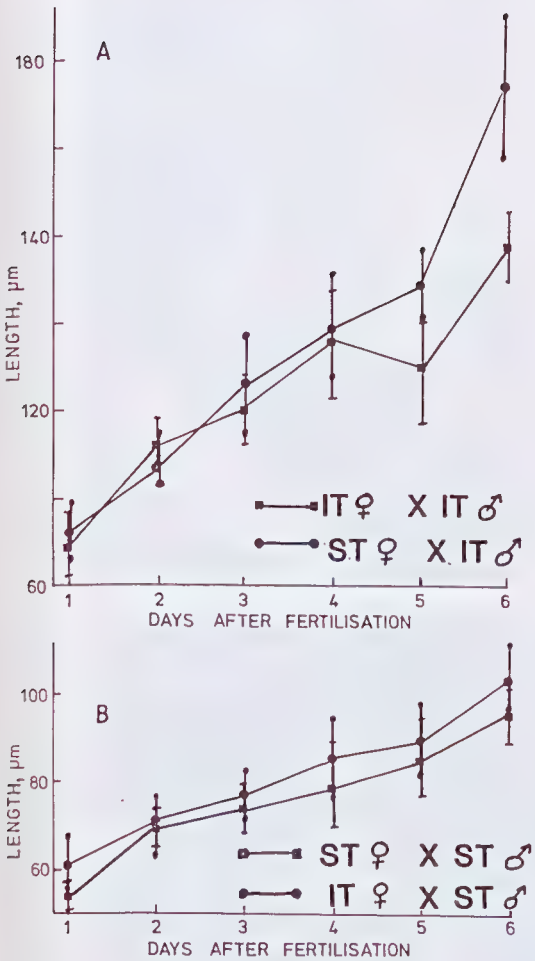

FIG. 1 — (A) The increase in length over time of germlings resulting from crossing eggs and sperm of intertidal (IT) plants, and eggs of subtidal (ST) plants with sperm of intertidal plants. (B) The increase in length over time of germlings resulting from crossing eggs and sperm of subtidal plants and eggs of intertidal plants with sperm of subtidal plants.

the germlings become spatula-shaped. Numerous rhizoids (plate 7D) provide a strong anchorage for the young plants.

DISCUSSION

Development of conceptacles and gametangia in *Durvillaea antarctica* from Macquarie Island is similar to that described for *D. potatorum* (Clayton *et al.* 1987). Variation occurs in the timing of reproduction. Environmental stimuli, especially day length, have been shown to affect receptacle initiation and conceptacle development in the fucoid genera *Ascophyllum nodisum* (Terry & Moss 1981) and *Fucus distichus* (Bird & McLachlan 1976). These genera initiate receptacles when day length is less than 12 hours. The reproductive pattern of *D. potatorum* is consistent with a day length requirement of 12 hours or less for conceptacle maturation (Clayton *et al.* 1987). Reproduction in *Durvillaea antarctica* may also be related to environmental stimuli, but if so they are different from those affecting the closely related genera mentioned. Naylor (1953) noted that conceptacles of *Durvillaea antarctica* in New Zealand which were initiated in June (winter) did not become fertile until the following April. This may indicate that longer day lengths are necessary for gamete maturation in *Durvillaea antarctica*. Gametes of *Durvillaea antarctica* from Macquarie Island are initiated and mature during summer and autumn, when day lengths range between 16 and 20 hours. The plants remain fertile and appear to be initiating gametes when day lengths are as low as 4–5 hours. Climate may be related to the variations in reproduction described. Blackler (1955) described the fertile period of some Fucaceae becoming later and longer with increasing latitude. *Durvillaea antarctica* at Kerguelen Island releases gametes throughout the summer (Delépine 1964). In the South Island of New Zealand, *Durvillaea antarctica* releases gametes from late autumn (April) to early spring (August–September), with a peak release in midwinter (Hay 1979). Hay (1977) suggested that the reproductive period of *Durvillaea antarctica* becomes more protracted with increasing latitude, a suggestion supported by results from the present study. The ability to maintain fertility for longer periods may relate to the more stable water temperatures occurring at higher latitudes.

At present the genus *Durvillaea* contains four species: *D. antarctica*, *D. willana*, *D. chathamensis* and *D. potatorum*. Hay (1979) suggested the possibility of a new species from Antipodes Island. Cheshire (1985) described significant morphological variation yet gradation between populations of *D. potatorum* from different locations. Plants growing in the intertidal area are subjected to physical stresses from wave action that do not affect plants growing subtidally. The ability of intertidal *Durvillaea antarctica* plants to float allows them to "ride" over the waves, and this may lessen the physical stresses on the plants.

For any plant growing in such a turbulent environment the ability to attach and grow rapidly

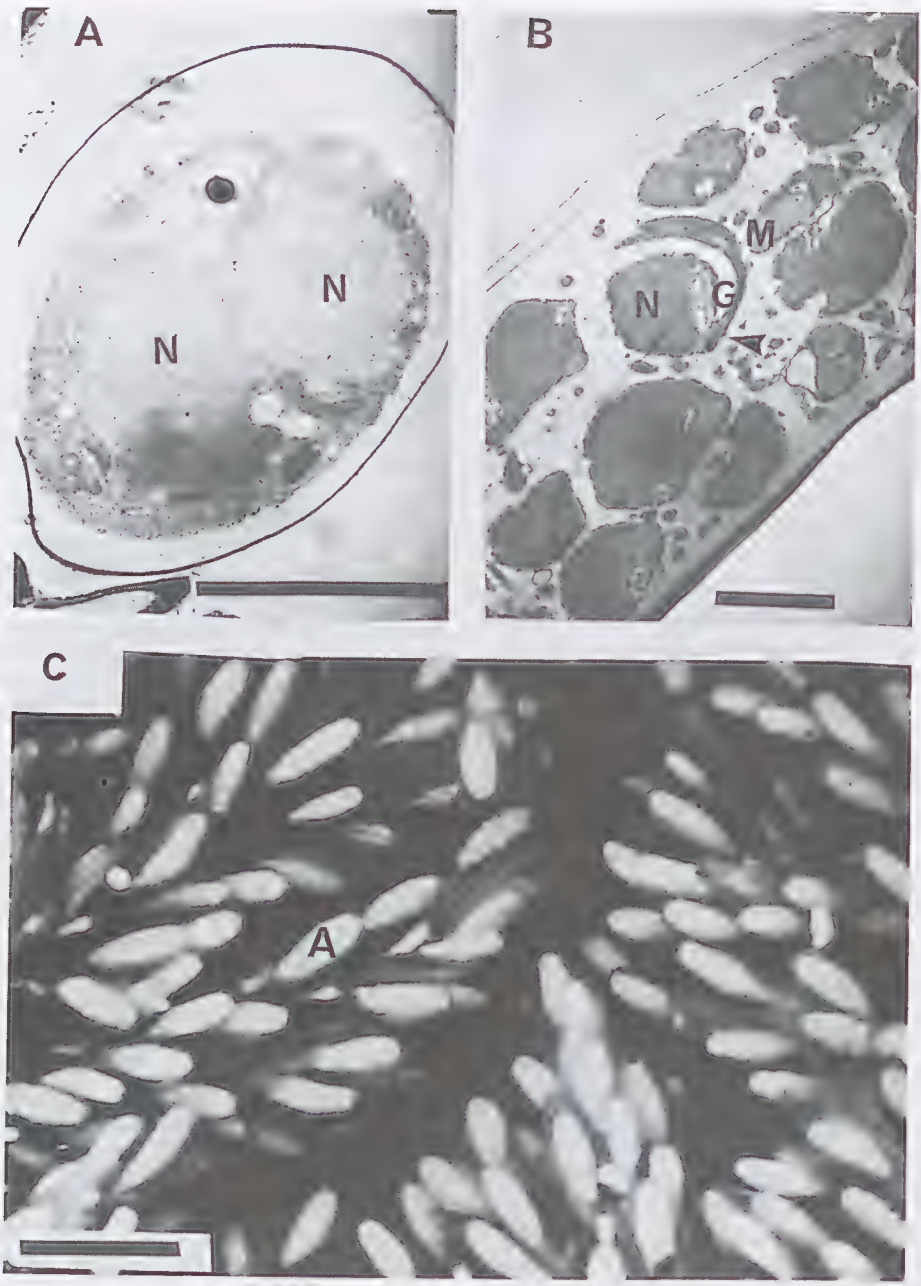

PLATE 4

A: Transmission electron micrograph of a young antheridium showing two of the four nuclei (N) surrounding cytoplasm. Bar = 5 μm.
B: Transmission electron micrograph of a mature antheridium showing individualised sperm containing a nucleus (N), mitochondria (M) and a Golgi body (G). The flagellar insertion is arrowed. Bar = 2 μm.
C: Scanning electron micrograph showing mature antheridia (A) in a male conceptacle. Bar = 20 μm.

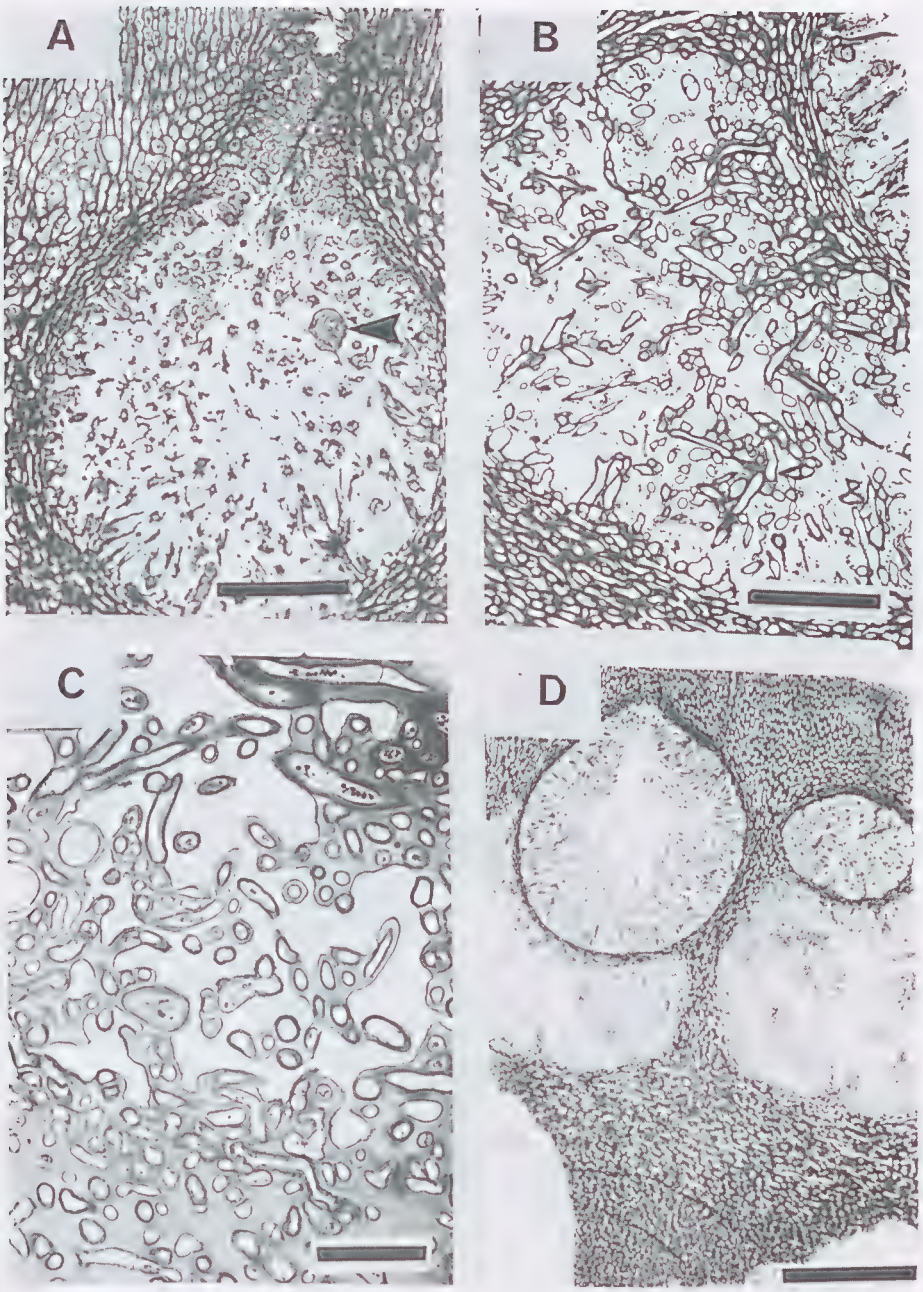

PLATE 5

A: An empty conceptacle, showing an aborted oogonium (arrowed) and filaments which block the ostiole. Bar = 50 μm.
B: Light micrograph showing development of filaments in an empty conceptacle. Bar = 25 μm.
C: Light micrograph showing development of intercellular matrix in an empty conceptacle. Bar = 10 μm.
D: Light micrograph showing current season's conceptacle developing into the space occupied by a senescent conceptacle. Bar = 150 μm.

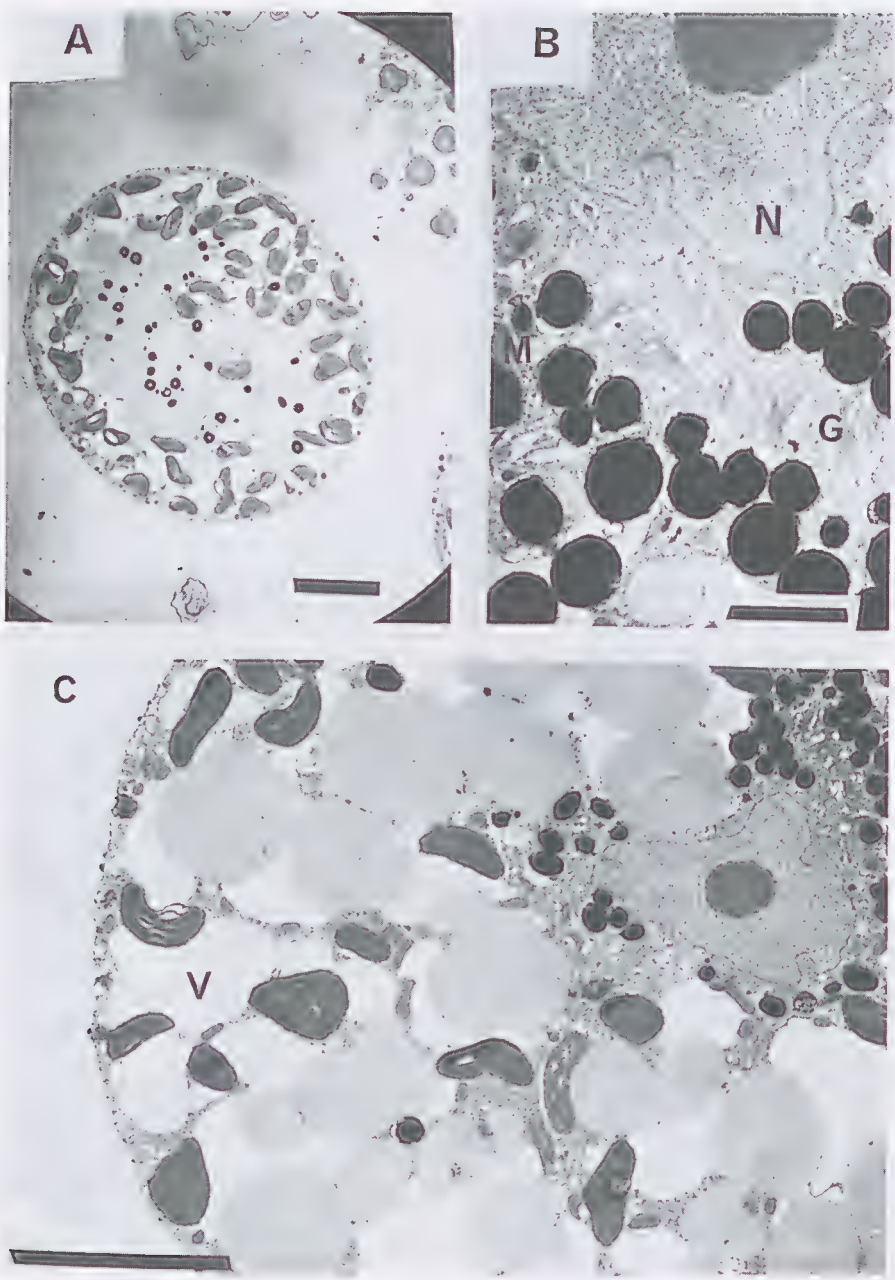

PLATE 6

A: Released egg of D. antarctica *which has rounded up. Bar = 10 μm.*
B: Nucleus (N) of a released egg surrounded by cytoplasm including mitochondria (M) and Golgi bodies (G). Bar = 2 μm.
C: Transmission electron micrograph of a released egg of D. antarctica *showing vacuoles (V) and chloroplasts (C). Bar = 10 μm.*

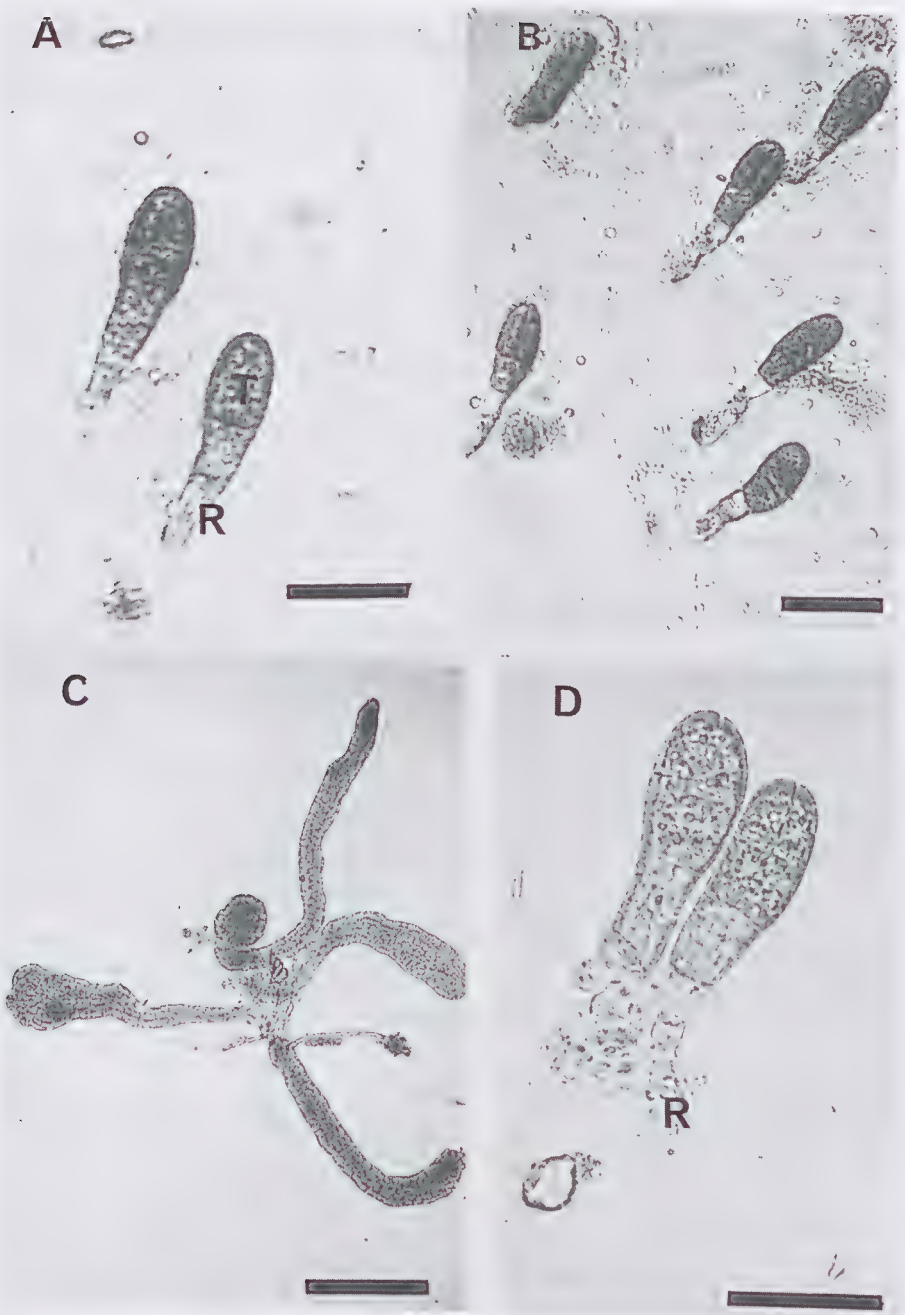

PLATE 7

A: Rhizoid (R) and presumptive thallus (T) in 24-hour-old germlings of D. antarctica. *Bar = 35 μm.*
B: 48-hour-old D. antarctica *germlings with longitudinal divisions in the thallus. Bar = 50 μm.*
C: Flattened thalli of four-week-old D. antarctica *germlings. Bar = 100 μm.*
D: Rhizoids (R) in three-day-old germlings of D. antarctica. *Bar = 50 μm.*

is important; without a secure attachment young plants can be dislodged by water movement and abrasion by fronds of larger plants. Examination of germling growth rates in the first six days after fertilisation showed that intertidal germlings grew faster than subtidal germlings, perhaps as a response to variation in the environment. The intertidal area receives more light, and water movement would provide greater oxygenation and nutrient availability. A genetic component to this variation is also indicated by the results, as crosses between the two forms have different growth rates. The variations appear to be associated with the male gamete. For *Durvillaea antarctica* at Macquarie Island, having genetic adaptations to the environment "sperm-linked" may be an advantage. Sperm of Durvillaea do not exhibit a phototactic response, i.e. they swim neither towards nor away from light. With this in mind, more sperm released from intertidal plants would remain near the surface, while more sperm of subtidal plants would remain near the bottom. Regardless of whether sperm fertilised eggs from subtidal or intertidal plants, fertilisation should occur at the area most suitable for growth.

The ability of germlings to adhere and grow rapidly is due in part to the immediate photosynthetic competence of the zygotes and utilisation of storage products located in egg vacuoles. Early development of *Durvillaea antarctica* germlings is similar to, but distinct from that of closely related fucoid algae. Attachment and initial division patterns are almost identical to those of *Fucus* (Brawley *et al.* 1976), *Hormosira* (Forbes & Hallam 1979), *Pelvetia* (Moss 1974), *Ascophyllum* (Moss 1975) and *Cystophora* (pers. obs.). The fucoid algae develop apical hairs and differentiate an apical cell within a week or two of fertilisation. Growth of *Durvillaea* germlings remains diffuse, as it is in adult plants. The germlings become flattened and morphologically identifiable as *Durvillaea* after approximately a month of growth.

CONCLUSION

Although significant morphological variation exists between the intertidal and subtidal forms of *Durvillaea antarctica* from Macquarie Island, due to the common occurrence of intergrades and successful cross-fertilisation between the two forms, it is felt that they should be retained as the same species. The variations which exist are more likely to be adaptations to different conditions occurring in the habitats of the plants.

REFERENCES

BIRD, N.L. & McLACHLAN, J., 1976: Control of formation of receptacles in *Fucus distichus* L. subsp. *distichus* (Phaeophyceae, Fucales). *Phycologia*, 15: 79–84.

BLACKER, H., 1955: Observations on the time of reproduction and rate of growth of certain fucaceae. *Proc. 2nd Int. Seaweed Symp. (Trondheim)*: 158–162.

BRAWLEY, S.H., WETHERBEE, R. & QUATRANO, R.S., 1976: Fine structural studies of the gametes and embyro of *Fucus vesiculosis* L. (Phaeophyta) II. The cytoplasm of the egg and young zygote. *J. Cell Sci.*, 20: 255–271.

CHESHIRE, A.C., 1985: The biology of *Durvillaea potatorum*. Unpublished Ph.D. thesis, Monash University.

CLAYTON, M.N., HALLAM, N.D. & SHANKLY, C.M., 1987: The seasonal pattern of conceptacle development and gamete maturation in *Durvillaea potatorum* (Durvillaeales, Phaeophyta). *Phycologia*, 26(1): 35–45.

DELÉPINE, R., 1964: Le genre Durvillea dans les isles Australes Françaises. *Comité Nat. français des Rech. Antarct.*, 1(7): 141–147.

FORBES, M.A. & HALLAM, N.D., 1979: Embryogenesis and substratum adhesion in the brown alga *Hormosira banksii* (Turner) Decaisne. *Br. Phycol. J.*, 14: 69–81.

HALLAM, N.D. & LUFF, S.E., 1988: The fixation and infiltration of the larger brown algae (Phaeophyta) for electron microscopy. *Br. Phycol. J.*, in press.

HAY, C.H., 1977: A biological study of *Durvillaea antarctica* (Chamisso) Hariot and *D. willana* Lindauer in New Zealand. Unpublished Ph.D. thesis, University of Canterbury.

HAY, C.H., 1979: Nomenclature and taxonomy within the genus Durvillaea Bory (Phaeophyceae: Durvillaeales Petrov.) *Phycologia*, 18: 191–202.

MOSS, B.L., 1984: Attachment and germination of the zygotes of *Pelvetia caniliculata*. *Phycologia*, 13(4): 317–322.

MOSS, B.L., 1975: Attachment of zygotes and germlings of *Ascophyllum nodosum*. *Phycologia*, 14(2): 75–80.

MULLER, D.G., CLAYTON, M.N., GASSMANN, G., BOLAND, W., MARNER, F.-J., SCHOTTEN, T. & JAENICKE, L., 1985: Cystophorene and hormosirene, sperm attractants in Australian Brown Algae. *Naturwissenschaften*, 72: 97–99.

NAYLOR, M., 1953: The New Zealand species of *Durvillea*. *Trans. R. Soc. N.Z.*, 80: 277–297.

REYNOLDS, E.S., 1963: The use of lead citrate at high pH as an electron opaque stain in electron microscopy. *J. Cell. Biol.*, 17: 208–212.

TERRY, L.A. & MOSS, B.L., 1981: The effect of irradiance and temperature on the germination of four species of the Fucales. *Br. Phycol. J.*, 16(2): 143–151.

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DEVELOPMENTS IN THE STUDIES OF SUBANTARCTIC SHORES, WITH PARTICULAR REFERENCE TO MACQUARIE ISLAND

by R. D. Simpson

(with two text-figures)

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Subantarctic seashores are limited to part of the South American peninsula and a number of islands stretching across a vast oceanic expanse. This isolation and subpolar climate are important in determining the organisms forming the seashore communities of the region and their strategies for survival.

Records of biota from subantarctic shores are now reasonably extensive. Findings from studies at Australian, French and South African bases have given rise to biogeographical hypotheses about this remote region and its relationships with distant temperate and antarctic areas. Macquarie Island has been prominent in this work, with the first systematic observations being undertaken in 1948–50 and a number of studies following at widely separated times.

In all subantarctic locations, further careful collecting of some groups will enhance taxonomic work and interpretations of distributions of marine organisms. However, more specific work, with increasing attention to life history, ecological, physiological and biochemical studies, could resolve the ways in which organisms have arrived at, and cope with, this particular environment. With so few islands scattered around the globe in this region, Macquarie Island and all subantarctic localities have much to offer, both individually and for comparison.

Key Words: subantarctic seashores, subantarctic inshores, marine organisms, biota, Macquarie Island.

INTRODUCTION

Studies of the seashore at Macquarie Island follow a similar pattern to those for all the shores of the subantarctic region — particularly for the islands that are scattered across the ocean.

Collections from a number of expeditions during this century provided the first substantial sets of marine biological material. However, it was not until the establishment of bases on the islands (from the 1940's on) that each location could receive the sort of attention that had been given to shores elsewhere.

What has been the progression of this work? The approach is not different from what has happened in other biological/ecological studies. The prime difference occurs through the isolation and the logistic difficulties, causing the state of knowledge to be considerably behind that of more accessible regions. So why repeat the process for the subantarctic region? Simply to describe new fauna and flora or, hopefully, to uncover new principles and patterns for the ecology of marine organisms?

INSHORE MARINE STUDIES IN THE SUBANTARCTIC REGION

Macquarie Island

Firstly, what is the state of work in the subantarctic inshore environment — using Macquarie Island as a reference point? Organisms were first collected from Macquarie Island shores at the end of the nineteenth century. Extensive collections were made during the Australasian Antarctic Expedition of 1911–13. After the establishment of a base on Macquarie Island by the Australian National Antarctic Research Expedition (ANARE), collections of intertidal biota were made by Kenny & Haysom (in the period 1948–50), by Bennett & Macpherson (in 1959) and by Vestjens (in 1961–62). Up to this point, the status of Macquarie Island marine biology, for both flora and fauna, was confined to the acknowledgement of collectors in various taxonomic works.

Kenny & Haysom (1962) presented an ecology of the rocky shores, primarily by way of delineating the recognisable zones down the seashore, with notes of interest and speculation on some groups. The observation and recording of zonation of organisms formed a prominent part of seashore

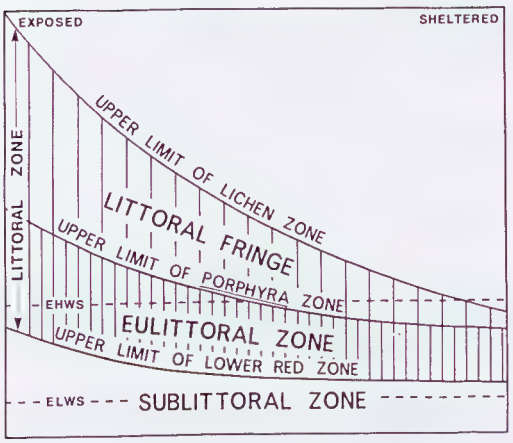

FIG. 1 — Zonation of Macquarie Island rocky shores, in relation to a universal zonation scheme. EHWS: extreme high-water spring tidal mark; ELWS: extreme low-water spring tidal mark. Local zones corresponding to universal zones: littoral fringe = Lichen zone; eulittoral zone = Porphyra *zone, bare zone, zone of red algae, zone of* Durvillaea *holdfasts; sublittoral zone = zone of encrusting coralline algae.*

work at that time. Previous to Kenny and Haysom's publication, some notes on the seashore environment had appeared in Law & Burstall (1956), and Knox (1960, 1963) had included Macquarie Island in biogeographical reviews of the southern oceans, based on the knowledge of the biota of Macquarie Island at the time. Bennett (1971) reported on her observations and collecting on Macquarie Island's seashores; again, this primarily covered zonation and notes of biological interest for some groups.

The zonation of rocky shores of Macquarie Island was re-examined (Simpson 1976a) with a view to equating the recognisable zones with their ecological equivalents in a universal zonation scheme (Lewis 1961, 1964); the pattern found is presented in figure 1. Basically, the local zones of Kenny & Haysom (1962) were confirmed and some other zones recognised, depending on the topographies and orientations of the shore. These local zones could be aligned with the standard seashore zonal designations of maritime, littoral fringe, eulittoral and sublittoral, which can be set by the organisms themselves, that is by recognisable changes in community composition when proceeding down the shore. These divisions broadly correspond to the following conditions: terrestrial (maritime); influenced by the sea but primarily exposed to air (littoral fringe); influenced by the sea and primarily exposed to wetting (eulittoral); and usually covered by the sea (sublittoral). However, this does not mean that the associated changes in physical factors along this gradient are the sole determinants of biotic abundances and distributions — a view challenged by Underwood & Denley (1984).

As part of the studies reported immediately hereunder, the sublittoral region was explored for the first time by way of SCUBA diving. The sublittoral work had very specific orientations and goals around certain animals (molluscs and echinoderms) and has been reported in a number of publications, and in conjunction with later visits to the island (Simpson 1976b, 1977, 1982a, b, Simpson & Harrington 1985). A small team of biologists from the Australian Museum later undertook more general sublittoral collections around the island (Lowry *et al.* 1978). Much of the material from those collections has been channelled towards taxonomic specialists.

Apart from studies of the zonation of the island in relation to a universal zonation scheme, work has centred around the ecology of benthic invertebrates. The lines of research have been directed towards community composition and relationships with environmental factors (Simpson 1976b, 1985) and reproductive ecology (Simpson 1977, 1982a, b, Simpson & Harrington 1985), always comparing the findings with the ecology and reproductive strategies found in shore benthos of other regions.

The only other ecological work to be published on Macquarie Island seashores is by Chaloupka & Hall (1984), an appraisal of biotic distribution patterns in relation to tidal emersion (in the mould of work done elsewhere by Underwood (1978) but using different mathematical analysis). This work is a good example of how the logistic problems of subantarctic studies could have hidden effects on results. It was centred around recording the presence/absence of species along transects — for which correct positioning of the boundaries of distribution of species was of prime importance. However, it was performed during a "one-off" short period of a few days, totally inadequate to identify true boundaries without sufficient consideration of the peculiarities of the microenvironment and ecology of the species. Such inadequacies tend to become lost in the dazzle of subsequent mathematical analysis.

Chaloupka & Hall (1984) relied on the presence versus absence of species, in 0.25 m^2 quadrats set perpendicularly to the intertidal gradient, to set

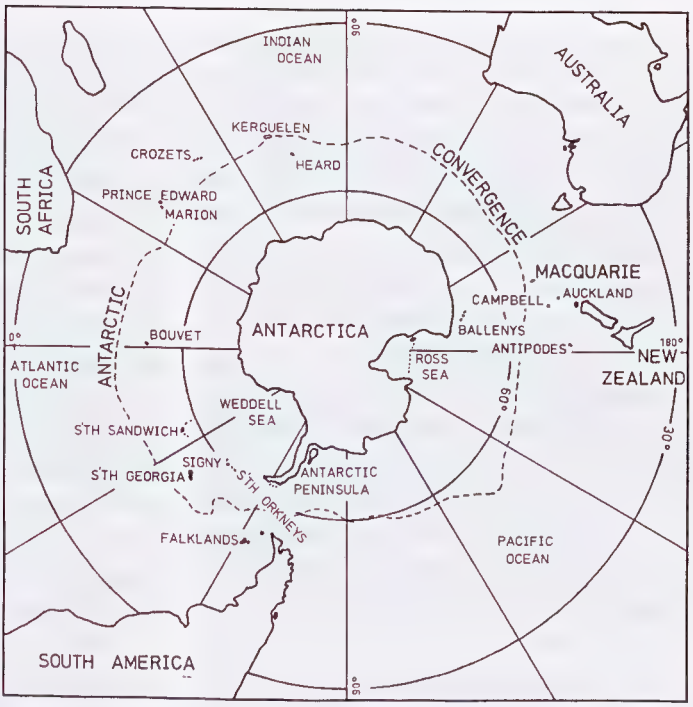

FIG. 2 — Location of Macquarie Island and other islands in the subantarctic and antarctic regions.

"boundaries" to distributions of species. However, without accompanying biological/ecological study of the species used, the actual question of what constitutes a boundary is left begging. Organisms do occur at levels away from their "subzone" of occupation in the intertidal zone on rocky shores (Simpson 1976a). Are these occurrences valid data points in relation to tidal rise and fall? Only if the topography is uniform. Small irregularites (crevices, etc.), which will facilitate disparate occupation by organisms with respect to direct equating to tidal rise and fall, are abundant in the geological formations of the rocky shores of Macquarie Island, with the exception of some sheer cliff faces. Also, seasonal changes do occur in vertical distributions of biota on Macquarie shores. Chaloupka and Hall cite Simpson (1976a) as implying that such changes do not occur, but this is a misunderstanding. The statement was that the zones did not change seasonally and it was made quite clear elsewhere in the paper that the zones were not set by the total vertical range of the species.

There was no compelling reason to do the work presented by Chaloupka & Hall (1984) at Macquarie Island. It would have been far better to determine boundaries to intertidal distributions for biota where either (a) much more is known about the biota, or (b) the accuracy of the boundaries can be subjected to checking over time. Expensive logistical support for subantarctic work warrants more than the usual vetting of research proposals (discussed further later in this paper).

Elsewhere in the Subantarctic Region

In other subantarctic locations, the pattern of progression of research in marine inshore biology has been very similar, that is, collections — taxonomic work — seashore descriptive studies —more specific ecological studies.

The literature on seashore ecology across the subantarctic started in the 1960's and the output has considerably increased over the last decade (Kerguelen Islands: Delépine 1963, Grua 1963, 1965, 1971, Arnaud 1974, Arnaud & Bandel 1978, Delépine *et al.* 1979, Guille & Laserre 1979, Bellido 1982, McClintock 1985, McClintock & Lawrence 1986. South African islands: Fuller 1967, Puskin 1975, de Villiers 1976, Grindley 1978, Blankley 1984, Blankley & Branch 1985, Blankley & Grindley 1985. New Zealand subantarctic islands: Knox 1968. Heard Island: Smith & Simpson 1985).

The catalyst for all these works was the establishment of bases on the subantarctic islands (see fig. 2 for the distribution of islands in the subantarctic region). At Heard Island, for example,

a base was established about the same time as that on Macquarie Island but was abandoned in the 1950's. Consequently, its isolation resulted in a very limited amount of work on its seashore ecology. Collections have been processed for taxonomic work, some notes on algal zones were included in a report by Law & Burstall (1953) and Chittleborough (1956) recorded results of some offshore work, but the shore environment was not adequately described until 1984 by Smith and Simpson. Thus, Heard Island remains at the "descriptive ecology" stage.

Surprisingly, work on the seashores of the subantarctic section of the South American peninsula is less than that for the islands. Knox (1968) gave a zonation pattern for Magellanic South America; Mendez & Cardoza (1986) examined the structure of intertidal communities of boulder beaches of islands in the Cape Horn archipelago. There have been several studies on temperate shores of South America and on the antarctic peninsula.

THE FEATURES OF INSHORE COMMUNITIES OF MACQUARIE ISLAND AND THE SUBANTARCTIC REGION

There are many similarities in the biotic composition of the shores across the subantarctic region. At the top of the shore, the littoral fringe is marked by a zone of lichens. In other climatic regions, littorinid molluscs form zones in the littoral fringe, but not on subantarctic shores. At the bottom of the shore, an encrusting coralline algae zone marks the upper limit of organisms that are truly marine. In between these two areas lies the eulittoral zone; throughout the subantarctic, various algal species dominate (cover more area than other organisms) to form conspicuous local subzones within the eulittoral zone.

The only animal to form a conspicuous subzone is the pulmonate limpet of the genus *Kerguelenella*. *Kerguelenella lateralis* dominates an area on Macquarie Island shores that was termed the Bare Zone by Kenny & Haysom (1962). The term "Bare" refers to the denuded rock surfaces of the zone. Strangely, Macquarie Island appears to be the only subantarctic location to show this non-algal zone. If its bareness is the result of the grazing action of the pulmonate limpet, this limpet does not exert the same influence on other subantarctic islands (Marion, Kerguelen) where it is also found. A Bare Zone was reported for Marion Island (higher up on the shore) by Fuller (1967), but this was later discounted by more detailed work by de Villiers (1976).

Two of the most frequent algae to form zones are the genus *Porphyra* — at the top of the eulittoral zone — and *Durvillaea antarctica* — at the bottom of the eulittoral zone. The zone of the giant *Durvillaea* virtually creates a protected environment under its giant fronds and many truly marine organisms progress further up the rocky shores under this protection (Simpson 1976a, b).

What of the organisms themselves? Benthic invertebrates of rocky shores have received the most investigation. There are two themes in ecological research particularly applicable to subantarctic studies: the local one — how organisms cope, including how they are distributed locally — and the geographical one — the distribution of organisms on a global scale.

The climate of the subantarctic is harsh but equable. Details of the typical subantarctic climate have been presented at many venues and it would be superfluous to repeat them here. Basically, the low temperatures, high winds, frequent precipitation and overcast conditions provide a marine environment (especially in the intertidal) in which one might expect to find unusual features exhibited by the occupants, but the expectations for new findings should not be too high; the discoveries of spectacularly different phenomena (such as the mini-ecosystems of sulphur-rich vents on the ocean floor) are now rare events. However, scientific excitement is a relative thing and subtle changes in ecological patterns and strategies still provide grounds for spirited hypotheses — even though the phenomena may be less spectacular.

The subantarctic seashore is a biologically rich environment and provides a wealth of subjects for research into ecological principles. Coupled with the unusual climate and isolation, this presents many questions for past and present work, such as the physical tolerances and biochemical composition of invertebrates, the emphasis of ecological factors (e.g. predation), and reproductive strategies (Simpson 1976b, 1977, 1985, Arnaud & Bandel 1978, Blankley 1981, Lawrence *et al.* 1984). Further taxonomic work is still required to improve the status of the catalogue of species of the region; this is a basic requirement for other studies.

Biological and ecological investigations should always maintain a central question: what influences can be attributed to the distinctive features of the subantarctic ecosystem — both locally and globally? That appears to be an obvious statement but the sentiment can easily be over-

looked. Logistic (and hence financial) difficulties dictate restricted support for scientific study in the subantarctic regions. Hence, lines of enquiry that can be accommodated by organisms and systems in more accessible areas should be directed to such areas. Research in the subantarctic region should be aimed at the peculiarities of the biota and their unusual environment.

One of the most promising lines of research in this regard is reproductive ecology. Thorson (1950) expounded the hypothesis that, in progression towards the colder regions of the higher latitudes, reproductive modes of marine invertebrates change towards a non-free form of larval development, i.e. via an egg case, brooding, or ovoviviparity. Ever since, there has been much speculation as to why this should be, with citations of deviations to this trend (Jablonski & Lutz 1983). Where it is evident (e.g. in molluscan and echinoderm taxa), investigation of the trend is in progress, involving studies of present-day ecology and phylogenetic affinities, coupled with hypotheses of evolutionary history.

For example, many species of starfish in the Southern Ocean brood their young. However, in the antarctic, current work (Pearse, pers. comm.) indicates that whether a starfish species broods its young or releases a larval form into the water is correlated with the taxonomic group to which it belongs; i.e. there could well be a phylogenetic restriction on the modes of reproduction available to a particular group. With the two reproductive modes existing in starfish in cold climates, what advantages does one mode have over the other? This question applies to other invertebrates as well. If the increased frequency of a protective mode of reproduction is a reality, does it simply allow better (or further) exploitation of resources? How do the free-larvae distributing forms (of which there are many species) cope? Is it primarily a question of history, i.e. that past events such as ice ages have favoured survival of species with no free larvae and other forms have slowly re-established, with present-day ecological criteria having few determining roles?

One element of littoral studies that attracted much attention in the 1960's was biogeographical affinities (Knox 1960, 1963). A number of biogeographical zones have been drawn up to include organisms with minimal differences; these zones provide an initial descriptive framework for the distribution of organisms over large areas. However, it must be remembered that the zones represent an imprecise description of complex mixtures of species that show some predictability of affinities. The zones themselves do not offer any ecological explanations.

The distribution of organisms across and within the subantarctic region can be matched with biological and ecological features of the organisms, their phylogenetic history, and past climatic events, to arrive at interpretations for present community structures and even for predictions of the effects of possible future events.

The factor of isolation of the subantarctic islands presents many avenues of study. For instance, some marine invertebrates are widely distributed; stretching across the entire oceanic expanse of the subantarctic; yet their reproductive modes do not allow for dispersal of oceanic larvae. For many species, dispersal appears to be via adults attached to algae that circumnavigate the Southern Ocean (Arnaud 1974, Simpson & Harrington 1985), a chancy business in such a vast expanse of ocean with so little land mass. Edgar (1986) points out that organisms arriving by chance would undergo independent evolution and be expected to differentiate relatively quickly into separate species, whereas species that maintain gene flow should retain their specific identity over much longer periods. Biochemical and genetic studies would provide insights into the relatedness or otherwise of populations of such animals. A particularly suitable species for such work is the small chiton *Hemiarthrum setulosum*, which broods its young in the pallial groove to a juvenile stage and then releases them on the rocky substrate (Simpson 1977). Despite this restricted means of dispersal at the recruitment phase, *H. setulosum* has a wide circum-subantarctic distribution, with possible transport via occupation of *Durvillaea* holdfasts adrift in the Southern Ocean.

One of the banes of the contemporary world is pollution, i.e. the intrusion of contaminants or disturbance of environmental factors, from human activities. The antarctic biota have received considerable attention over recent years with respect to the measurement of various contaminants, particularly organochlorines, in seabirds and seals (e.g., Luke *et al.* 1984). These revelations have had quite an impact, in that such isolated animals could be so affected by these contaminants, although there is some evidence that the animals may be exposed to contaminants during migration to northern areas. There have been no reported studies on biological monitoring for pollution in marine invertebrates (or any other permanent residents) in the subantarctic region. Some present work on Macquarie Island marine invertebrates includes measurement of levels of metal pollutants in the flesh of molluscs

and holothuroids (R.D. Simpson, unpublished). Results for Cu, Pb, Zn, Cd and Hg have shown similar or lower levels to those found in limpets and echinoderms in other marine environments remote from sources of pollution. One exception was high levels of Zn in the Macquarie Island holothuroid *Pseudopsolus macquariensis*, where a mean value of 484 μg/g Zn (dry weight) was recorded from pooled samples. Although echinoderms do naturally accumulate high levels of Zn, the above value is unusually high and requires further investigation. Certainly, subantarctic marine organisms could provide biological sentinels for any southern oceanic dispersal of contaminants.

For any of the above topics, the subantarctic inshore communities represent a "half-way house" between the temperate and antarctic communities. Hence, the subantarctic regions will continue to provide an important link in research into any possible gradient of climatic influences in ecology, physiology and biogeographical distribution, past and present.

REFERENCES

ARNAUD, P.M., 1974: Contribution a la bionome marine benthique des régions antarctiques et subantarctiques. *Tethys*, 6: 456–656.

ARNAUD, P.M. & BANDEL, K., 1978: Comments on six species of marine Antarctic Littorinacea (Mollusca, Gastropoda). *Tethys*, 8(3): 213–230.

BELLIDO, A., 1982: Biocenoses of rocky shores on Kerguelen Islands. Colloque sur les ecosystèmes subantarctiques. *CNFRA*, No.51: 81–92.

BENNETT, I., 1971: *SHORES OF MACQUARIE ISLAND*. Rigby Ltd, Sydney: 69 pp.

BLANKLEY, W.O., 1981: Marine food of kelp gulls, lesser sheathbills and imperial cormorants at Marion Island (Subantarctic). *Cormorant*, 9: 77–84.

BLANKLEY, W.O., 1984: Ecology of the starfish (*Anasterias rupicola*) at Marion Island. *Mar. Ecol. Prog. Ser.*, 18: 131–137.

BLANKLEY, W.O. & BRANCH, G.M., 1985: Ecology of the limpet *Nacella delesserti* at Marion Island in the subantarctic Southern Ocean. *J. Exp. Mar. Biol. Ecol.*, 92: 259–281.

BLANKLEY, W.O. & GRINDLEY, J.R., 1985: Intertidal and shallow subtidal food web at Marion Island. Antarctic nutrient cycles and food webs. *In* Siegfried, W.R., Condy, P.R. & Laws, R.M. (Eds): *PROCEEDINGS OF THE 4TH SCAR SYMPOSIUM ON ANTARCTIC BIOLOGY*. Springer-Verlag, Berlin: 630–636.

CHALUPKA, M.Y. & HALL, D.N., 1984: Examination of species dispersion patterns along the intertidal gradient on Macquarie Island using a restricted occupancy model. *J. Exp. Mar. Biol. Ecol.*, 84(2): 133–143.

CHITTLEBOROUGH, R.G., 1956: The settlement of marine organisms on submerged surfaces at Heard Island, 1949. *ANARE Interim Rep.*, 15, Pub. No.30: 67–81.

DELÉPINE, R., 1963: Un aspect des études de biologie marine dans les iles Australes françaises. I. La zonation marine. *CNFRA*, 3: 3–12.

DELÉPINE, R., IMBAULT, D. & PADOVANI, A., 1979: Experimental data on the influence of wetting shore ecology: a case study from the Kerguelen Islands. *Vie et Milieu*, 28/29(3–AB): 404–424.

EDGAR, G.J., 1986: Biogeographical processes in the Southern Hemisphere marine environment. *Actas Congr. Algas mar. Chilenas*: 29–46.

FULLER, N.R., 1967: A preliminary report on the littoral ecology of the Marion and Prince Edward Islands. *S. Afr. J. Sci.*, 63: 248–253.

GRINDLEY, J.R., 1978: Marine ecosystems of Marion Island. *S. Afr. J. Ant. Res.*, 8: 38–42.

GRUA, P., 1963: Etude de biotopes marine infralittoraux Kerguelen 1962–63. *TAAF Paris*, No.23–24: 69–73.

GRUA, P., 1965: Écologie infralittorale a Kerguelen en scaphandre autonome. *TAAF Paris*, No.30: 74–79.

GRUA, P., 1971: Introduction écologique. *In* Invertébrés de l'infralittoral rocheux dans l'Archipel de Kerguelen. *CNFRA*, 30: 1–66.

GUILLE, A. & LASSERRE, P., 1979: Oxygen consumption of the sea urchin *Abatus cordatus* and the oxidative property of its biotope on Kerguelen Islands. *Paris Mus. Nat. d'hist. nat. Mem.*, ser. C, Sciences de la terre, 3: 211–219.

JABLONSKI, D. & LUTZ, R.A., 1983: Larval ecology of marine benthic invertebrates: paleobiological implications. *Biol. Rev.*, 58: 21–89.

KENNY, R. & HAYSOM, N., 1962: Ecology of rocky shore organisms at Macquarie Island. *Pacif. Sci.*, 16: 245–263.

KNOX, G.A., 1960: Littoral ecology and biogeography of the Southern Oceans. *Proc. R. Soc.*, Ser. B, 152: 577–624.

KNOX, G.A., 1963: The biogeography and intertidal ecology of the Australasian coasts. *Oceanogr. Mar. Bio. Ann. Rev.*, 1: 341–404.

KNOX, G.A., 1968: Tides and intertidal zones. *In SYMPOSIUM ON ANTARCTIC OCEANOGRAPHY, SANTIAGO, CHILE, SEPTEMBER 13–16, 1966*. Scott Polar Research Institute, Cambridge: 131–146.

LAW, P.G. & BURSTALL, T., 1953: Heard Island. *ANARE Interim Rep.*, 7, Pub. No. 12.

LAW, P.G. & BURSTALL, T., 1956: Macquarie Island. *ANARE Interim Rep.*, 14, Pub. No.29.

LAWRENCE, J.M., McCLINTOCK, J.B. & GUILLE, A., 1984: Organic level and caloric content of eggs of a brooding asteroid and an echinoid from

Kerguelen (South Indian Ocean). *Int. J. Invert. Rep. Devel.*, 7(4): 249–257.

LEWIS, J.R., 1961: The littoral zone on rocky shores —a biological or physical entity? *Oikos*, 12: 280–301.

LEWIS, J.R., 1964: *THE ECOLOGY OF ROCKY SHORE.* English Universities Press, London: 323 pp.

LOWRY, J.K., HORNING, D.S., POORE, G.C.B. & RICKER, R.W., 1978: *THE AUSTRALIAN MUSEUM MACQUARIE ISLAND EXPEDITION, SUMMER 1977–78.* Australian Museum Trust, Sydney: 152 pp.

LUKE, B.G., JOHNSTONE, G.W. & RICHARDS, J.C., 1984 (Abstract): Organochlorine residues in Antarctic birds and seals. *VESTFOLD HILLS SYMPOSIUM.* Australian Antarctic Division, Hobart.

McCLINTOCK, J.B., 1985: Avoidance and escape responses of the subantarctic limpet *Nacella edgari* to the sea star *Anasterias perrieri. Polar Biol.*, 4(2): 95–98.

McCLINTOCK, J.B. & LAWRENCE, J.M., 1986: Movement patterns of the subantarctic pulmonate limpet *Kerguelenella lateralis* (Gould). *Polar Biol.*, 5(3): 135–138.

MENDEZ, L.G. & CARDOZA, C.R., 1986: [title translated] Structure analysis in intertidal communities of the Cabo de Hornos Archipelago: rock and boulder environment. *Estud. Oceanol.*, 5: 67–105.

PUSHKIN, A.F., 1975: Hydrobiological investigation of the littoral and upper portions of the sublittoral on Kerguelen Island. *Sovetskaia antarcticheskaia ekspeditsiia*, 91: 85–90.

SIMPSON, R.D., 1976a: The shore environment of Macquarie Island. *ANARE Rep.*, Ser.B(1), 125: 1–41.

SIMPSON, R.D., 1976b: Physical and biotic factors limiting the distribution and abundance of littoral molluscs on Macquarie Island (sub-Antarctic). *J. Exp. Mar. Biol. Ecol.*, 21: 11–49.

SIMPSON, R.D., 1977: The reproduction of some littoral molluscs from Macquarie Island (sub-Antarctic). *Mar. Biol.*, 44: 125–142.

SIMPSON, R.D., 1982a: Reproduction and lipids in the sub-Antarctic limpet *Nacella (Patinigera) macquariensis*, Finlay, 1927. *J. Exp. Mar. Biol. Ecol.*, 56: 33–48.

SIMPSON, R.D., 1982b: The reproduction of some echinoderms from Macquarie Island. *Aust. Mus. Mem.*, 16: 39–52.

SIMPSON, R.D., 1985: The relationship between allometric growth with respect to shell height and habitats for two patellid limpets, *Nacella (Patinigera) macquariensis*, Finlay, 1927 and *Cellana tramoserica* (Holten, 1802). *Veliger*, 28: 18–27.

SIMPSON, R.D. & HARRINGTON, S.A., 1985: Egg masses of three gastropods, *Kerguelenella lateralis* (Siphonariidae), *Laevilitorinia caliginosa* and *Macquariella hamiltoni* (Littorinidae), from Macquarie Island (sub-Antarctic). *J. Malacol. Soc. Aust.*, 7: 17–28.

SMITH, J.M.B. & SIMPSON, R.D., 1985: Biotic zonation of rocky shores of Heard Island. *Polar Biol.*, 4: 89–94.

THORSEN, G., 1950: Reproductive and larval ecology of marine bottom invertebrates. *Biol. Rev.*, 25: 1–45.

UNDERWOOD, A.J., 1978: A refutation of critical tidal levels as determinants of the structure of intertidal communities on British shores. *J. Exp. Mar. Biol. Ecol.*, 33: 261–276.

UNDERWOOD, A.J. & DENLEY, E.J., 1984: Paradigms, explanations, and generalizations in models for the structure of intertidal communities on rocky shores. *In* Strong, D.R., Simberloff, D., Abele, L.G. & Thistle, A.B. (Eds): *ECOLOGICAL COMMUNITIES: CONCEPTUAL ISSUES AND THE EVIDENCE.* Princeton University Press, Princeton: 151–180.

DE VILLIERS, A.F., 1976: Littoral ecology of Marion and Prince Edward Islands. *S. Afr. J. Ant. Res., Suppl.*, 1: 1–40.

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THE OFFSHORE FAUNA OF MACQUARIE ISLAND: HISTORY AND BIOGEOGRAPHY — RESULTS FROM NEW ZEALAND AND UNITED STATES RESEARCH CRUISES

by Elliot W. Dawson

(with one table)

DAWSON, E.W., 1988 (viii): The offshore fauna of Macquarie Island: history and biogeography results from New Zealand and United States research cruises. *Pap. Proc. R. Soc. Tasm.*, 122(1): 219–232. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Formerly New Zealand Oceanographic Institute, now Division of Marine and Freshwater Science, Department of Scientific and Industrial Research, Kilbirnie, Wellington, New Zealand.

For the past 50 years, knowledge of the offshore marine invertebrate fauna of Macquarie Island and speculation on its origin and relationships have rested almost entirely on the contents of a dredge haul taken by BANZARE in 1930. New information is now appearing, based on NZOI cruises, particularly in 1965, when New Zealand and the United States occupied a coincidental series of benthic stations in this area.

The history of investigations is outlined. The biogeographic findings from more widely based recent studies suggest relationships of shallower water and littoral species with the circum-subantarctic, and of the deeper water groups with northern or cosmopolitan species. Nevertheless, Macquarie Island stands as a distinctive biogeographic unit.

The Macquarie Ridge is a faunal movement route, and long-distance dispersal is probably assisted by Southern Ocean water circulation.

Key Words: biogeography, marine benthos, Stylasterina, Scleractinia, Mollusca, Brachiopoda, Echinodermata, Lithodidae, Macquarie Island.

PROLOGUE

> "It is my most deliberate conviction that nothing would aid more, Natural History, than carefully collecting and investigating all the productions of the most isolated islands, especially of the southern hemisphere ... Every sea-shell and insect and plant is of value from such spots."
> [Letter from Charles Darwin to Sir Charles Lyell, 11 February 1857.]

Although Macquarie Island is indisputably part of Australia politically, New Zealand biologists have laid claim to it as a place of special biogeographical interest to them, in a tradition going back to 1880, when J.H. Scott, Professor of Anatomy and Physiology at Otago University, spend some days there (Scott 1883). He was followed by the Hamiltons — Augustus, the father, subsequently Director of the Colonial (later Dominion, now National) Museum in Wellington, and Harold, his son. The former's observations and collections, made during his short visit in 1894 (Hamilton 1895), laid the foundation for future studies of the molluscs of the island, while the latter, as a member of the Australasian Antarctic Expedition, 1911–14, made detailed observations on many aspects of the natural history of Macquarie Island. An earlier commemoration of their work, the joint patronymic for a species of chiton, *Hemiarthrum hamiltonorum* Iredale & Hull, 1932, is now recognised as *H. setulosum* Dall, 1876, but they are still recalled by Mt Hamilton, the highest point of Macquarie Island.

An inherent problem in attempting a full biogeographical synthesis for regions of great interest and importance is the frequent delay in the publication of results of expeditions (see *Nature* 1968, p.855); Macquarie Island is no exception to this. Kusakin (1968, p.329) noted that such syntheses required knowledge of the whole fauna and flora.

Since it is not possible to give such an overview, the present paper concentrates, initially, on the history of investigation of the Mollusca, probably the dominant (and so far the best documented) group of marine invertebrates, also tracing the history of marine biologicalexpeditions and the work of individual investigators.

Although the work, in 1821, of the Russian explorer, Thaddeus Bellingshausen, is regarded as the first scientific investigation of Macquarie Island, and a United States Exploring Expedition under Charles Wilkes called there in January 1840, it was

not until March 1894 that the first collections of marine molluscs were made, by Augustus Hamilton during one of the trading cruises of the ketch *Gratitude*. Further specimens were collected in February 1899 by Dr Daniel Colquhoun of Otago University, during a call by the New Zealand Government vessel *Tutanekai*; Suter (1913) included the 17 species then known in his *Manual of the New Zealand Mollusca*, thus firmly placing Macquarie Island in the New Zealand biogeographical scene.

However, the first systematically organised expedition to explore Macquarie Island was the Australasian Antarctic Expedition, 1911–14 (AAE). Harold Hamilton's collections, made during his long stay on Macquarie Island with this expedition, raised the total of marine species to 34, including 14 new species and one new variety, as subsequently described by Hedley (1916). Notable finds were the two characteristic bivalves, the cockle *Chione mawsoni* (now included in the genus Tawera) and the brightly-coloured fan-shell *Chlamys subantarctica* (subsequently known as *Chlamys* (*Zygochlamys*) *delicatulus*), a most important indicator of climatic conditions in southern New Zealand in Quaternary times (Beu *et al.* 1977). However, Hedley offered comments rather than detailed biogeographical analysis, but noted relationships with Kerguelen, the Falkland Islands and South Georgia.

The next marine biological visitors to Macquarie Island were from the *Discovery* in 1901 and the *Nimrod* in 1909. The *Terra Nova* did some offshore plankton tows in 1911 on the voyage to the Ross Sea, collecting some pteropod molluscs off Macquarie Island.

The British Australian New Zealand Antarctic Research Expedition, 1929–31 (BANZARE), spent the period 1–8 December 1930 at Macquarie Island and, in so doing, made a single but major contribution to the marine biology of the island, as described in the official account of the expedition (Price 1963, p.105). This was BANZARE Station 83, Lusitania Bay, which was to become much quoted as the source of speculation on the relationships of the Macquarie Island marine fauna, certainly as far as the Mollusca were concerned. Other groups of benthic animals were also taken at this station and subsequently described in BANZARE reports, but only Mollusca have so far been sufficiently analysed to be useful for biogeographical purposes.

Tomlin (1948) reported the total number of species of molluscs then known as 49, including two new species, one a gastropod of the genus *Maurea*; a great proportion of the species from Macquarie Island was taken in 69 m (BANZARE Station 83) in one haul of a large rectangular dredge (DRL). From this, Tomlin inferred that the Macquarie Island mollusca have a closer relationship with those of the Antarctic Continent than with those of any other area; although the new Trochid, *Maurea megaloprepes*, had affinity with the neozelanic Calliostomatinae, there was little else to show a New Zealand influence. Tomlin also cited five genera of gastropods, in particular, which, in his opinion, proved the connection was south polar.

This *Maurea* is of special interest now, since the genus, including species occurring on submarine high spots between Macquarie Island and New Zealand, is currently being studied by Marshall at the National Museum of New Zealand.

Powell (1955, 1957) revised Tomlin's work, as part of a wider study of antarctic and subantarctic molluscs. He changed many of Tomlin's identifications and noted that disclaiming a number of these antarctic determinations also nullified Tomlin's inference of a closer relationship with those of the Antarctic Continent. Powell concluded that *Tawera mawsoni*, *Chlamys delicatula* and several other species could be considered relicts of Macquarie Island's former closer geographical association with the New Zealand mainland. He further noted the surprise element represented by *Cymatona*. This genus of the continental shelf edge of eastern Australia has turned up again, and from an intermediate area, the Chatham Rise. It provided the basis for a subsequent important analysis by Beu (1978).

Powell always included Macquarie Island species in his various checklists of "New Zealand" molluscs (e.g. his handbook, Powell 1979). In 1955, he included Macquarie Island amongst his "southern islands of New Zealand", which he grouped in three biogeographic units or provinces. Macquarie Island was placed in a "Kerguelenian" Province (together with Kerguelen, Heard, Marion, Prince Edward and Crozet Islands), a classification greatly strengthened, Powell noted, by details of sea bottom topography then available; these showed Macquarie Island separated by deep water of some 2000–3000 fathoms from the "Antipodean" group of islands (Auckland, Campbell, Bounty and Antipodes) and the "Forsterian" Province (Otago, Stewart Island and the Snares). He believed too much stress had previously been laid on the influence of the West Wind Drift in the dispersal of kelp with its associated molluscs, since this was neither regular nor frequent, and the particular

molluscan genera most likely to be transported in this way had already developed local species at Macquarie Island. The benthic (or "offshore") molluscs known from Macquarie Island suggested to Powell a prior Neozelanic connection for all the New Zealand southern islands, including Macquarie. However, he did note that placing it in a Kerguelenian Province might later prove untenable, in which case Macquarie Island might merit provincial rank by itself.

Examination of the coloured figures of provincial limits in the Southern Ocean, as given by Hedgpeth (1969, fig. 10), shows the impracticality of drawing precise divisions across such a wide oceanic area, where there are only a few scattered island with limited extents of shelves and shores (and consequently limited habitats). Where real boundaries are likely to be determined by seasonally fluctuating hydrological convergence zones, as well as varied bottom topography, any attempt to delineate distinct biogeographical provinces to include both benthic and littoral species is likely to be of little practical use. Powell's conclusions (1955) on the distinctiveness of the Macquarie Island fauna were prophetic of what is now being found.

The findings of this phase of exploration on the molluscan fauna of Macquarie Island were recorded by Dell (1964), in reporting on collections made by the Australian National Antarctic Research Expedition (ANARE), which began a systematic study there in 1948. He concluded that the some 42 species which he recognised as the total from Macquarie Island (still largely from BANZARE Station 83) represented a faunal mixture with the following affinities: endemic — 27 species (64%); Kerguelen — 5 (12%); circum-subantarctic — 5 (12%); Heard Island — 2 (5%); New Zealand — 2 (5%); of no particular affinity — 1 (2%).

Of the 27 endemic species, he considered that 13 seemed closely allied to the New Zealand fauna, eight were probably circum-subantarctic in origin and two had antarctic relationships. Accordingly, he derived the Macquarie Island fauna from three sources — (1) New Zealand, (2) circum-subantarctic and (3) Kerguelen — but added that there had been sufficient isolation of Macquarie Island for a comparatively high degree of endemism to have developed.

Dell's final statment is important:

> "By including the fauna of Macquarie within any province such as the Kerguelenian it seems ... there is a very real danger of losing sight of its very distinctive elements and its diverse origin."

With the establishment by ANARE of facilities on the island itself, the next phase of exploration of the island and its environmens was to begin. Investigations on the biology of the shore molluscs and other invertebrates were done by Kenny & Haysom (1962), followed by an excellent series of studies by Simpson (references in Selkirk *et al.* 1986), and the recent useful summary of the limpet species by Ubaldi (1985).

MACQUARIE ISLAND BENTHOS — POST BANZARE

In the early 1960's, the New Zealand Oceanographic Institute (NZOI) investigated the sea floor to the south of New Zealand — its subantarctic region, to define the bottom topography, to sample and analyse the bottom-living animals and to try to reconstruct the geological history of the area from sediment and rock samples (Dawson 1963, 1964). New Zealand and United States naval and antarctic support vessels made several cruises across the area north of Macquarie Island to southwest of New Zealand, to verify the long-held belief that the island was separated by great depths from the New Zealand Plateau, since the presence of ridge-like structures to the south, towards the Antarctic Continent, and some suggested high spots not far to the north of the island indicated otherwise. A more or less continuous ridge was delineated, linking Macquarie Island to the New Zealand Plateau (Brodie & Dawson 1965). Now known as the Macquarie Ridge, this was found to extend for some 1800 km, from the continental slope of New Zealand off Fiordland to the triple junction made by this ridge joining with the Pacific–Antarctic Ridge and the Indian–Antarctic Ridge at 60°S, 161°E (Wanoa & Lewis 1972, p.85). Dredgings along the high spots of the northern ridge and the association of geological and biological features led to consideration of the possibility that benthic animals could have moved in either direction between New Zealand and Macquarie Island, giving some substance to earlier thoughts by Powell (1955).

As late as 1963, Adie illustrated the supposed gap (of depths to 4000 m) thought to separate Macquarie Island from New Zealand (Adie 1963, p.460, fig. 2). Brodie (1964, p.16, fig. 16) showed how Benson and others (e.g. Thomson 1918, chart) had interpreted this supposed barrier and its significance. The presence of a physical link, even though not entirely continuous, provided an immediate basis for resolving some of the biogeographical problems of the relationships of

Macquarie Island. The Macquarie Ridge has also been accepted by geophysicists as a major feature of plate tectonics in the evolution of the southwest Pacific (e.g. Cullen 1970a, Hayes 1972 [includes a detailed bathymetry of the "Macquarie Ridge complex" by Hayes & Talwani 1971], Griffiths & Varne 1972, Williamson 1974). A comprehensive study on the marine geology of this region (Summerhayes 1969), bathymetric charts of Macquarie Island (Cullen 1970b) and its oceanic setting (Summerhayes 1967), and the hydrological scene (Houtman 1967) now provide the background for future studies of the Macquarie region.

NEW FINDINGS

Between 1959 and 1965, NZOI dredged or trawled successfully at 47 benthic stations in the Macquarie region (ten other stations being abandoned due to the rugged sea floor off the west coast of Macquarie Island). Coincidentally, in January 1965, the US research ship *Eltanin* on its Cruise 16, trawled at ten positions in this area (three stations close to Macquarie Island, five to the north and northeast and two south of the island). Another four stations were occupied near Macquarie Island during the *Eltanin* Cruise 27 in February 1967.

Soviet expeditions have also visited Macquarie Island (see especially Petrovskaya 1970), though so far only a brief report on the evolution and biogeography of the shore amphipods (collected during a call of the Soviet Antarctic Expedition in the Ob in 1956) has appeared. The *Dimitry Mendeleev* occupied two stations off Macquarie Island during its 16th Expeditionary Cruise in January 1976; one of these, in 87 m, about 6 km northwest of the Bishop and Clerk Islands, yielded bivalves, brachiopods and lithodid crabs; another, about 16 km to the northeast, in 300 m, had coelenterates, bivalves, brachiopods and lithodids (K.R. Grange, pers. comm.).

The biological results from the New Zealand and United States cruises are now gradually appearing. The remainder of this paper draws attention to what has been published, so far, on the benthic fauna, and comments on the significance, in terms of new knowledge, of its contribution towards a synthesis of the biogeography of Macquarie Island and its environs.

ECHINODERMATA

The list of echinoderm species recorded from Macquarie Island (including shore collections) previously stood at 13: Asteroidea — 7 species (Koehler 1920, Clark 1962), including 3 from BANZARE station 83; Ophiuroidea — 4, all from Station 83 (Madsen 1967); Echinoidea — 1 (Koehler 1926); and Holothuroidea — 1 (Dendy 1896). No crinoids had been recorded.

Collections made during the NZOI cruises from 1959 to 1965 brought the known fauna to 35 species (including five species of crinoids). Of the 47 NZOI stations, 30 had echinoderms: Asteroidea — 17; Ophiuroidea — 22; Crinoidea — 7; Echinoidea — 11; and Holothuroidea — 8. Geographically, 23 of the species recorded were from the vicinity of Macquarie Island, 13 from Macquarie Ridge to the north, and 2 from south of the island itself.

These determinations formed a basis for biogeographical commentaries on the relationships of the New Zealand, subantarctic and antarctic faunas (Dawson 1965, 1968, 1970, 1982); full lists of identifications and localities were published by McKnight (1984). Pawson (1968a, b, 1969) discussed the origin and dispersal of the holothurian fauna of Macquarie Island and its associated ridges, based on nine species (including some earlier AAE and ANARE shore records not previously published, as well as two additional species taken by NZOI but not listed by McKnight).

Only one group of echinoderms (comatulid crinoids) taken by the *Eltanin* in this area has been reported on so far. Speel & Dearborn (1983) indentified comatulids from four stations near Macquarie Island including *Daidalometra arachnoides*, *Glyptometra inaequalis* and another, determined only as "Unidentified Antedon B" (also found near the Auckland Islands). A possible link for some antarctic comatulids with South America, through the Magellanic Region and the Scotia Arc, was noted.

Daidalometra arachnoides is known from the Sulu Archipelago (at 5°N, 119°E), through the Ceram and Timor Seas into the Tasman Sea, and south to off the Auckland and Campbell Islands; its southernmost record is on a deep part of the Macquarie Ridge, about 320 km north of Macquarie Island at 51°07′S, 162°03′E, in 1647–1665 m (known overall depth range is 22–2236 m).

Glyptometra inaequalis occurs from the Philippine Islands to Fiji, the Kermadec Islands and New Zealand (including the Chatham Rise to the east), to about 160 km south of Macquarie

TABLE 1

Biogeographical Affinities of Echinoderms from the Macquarie Region

Total number of species = 42.

	Asteroidea	Echinoidea	Ophiuroidea	Holothuroidea	Crinoidea
Number of species	14	2	11	9	6
Endemic to Macquarie Island	4			2	
New Zealand only	6	2		4	3
Subantarctic only	3		3	2	
New Zealand + subantarctic			3	1	
Antarctic	1		2		
Indo-West-Pacific			1		1
New Zealand + Indo-West-Pacific					2
Cosmopolitan (incl. New Zealand)			1		
Cosmopolitan (incl. subantarctic)			1		

Island at 56°21′S, 158°28′E, in 1574–1693 m, as well as off Tasmania. It also has been taken in the southern Pacific, at about 54°S, 140°W (overall depth range 362–1152 m).

Of the five species of crinoids, identified by McKnight (1984) from NZOI cruises in the Macquarie region but not included in earlier analyses (Dawson 1965, 1970), *Glyptometra inaequalis* was recorded from the Macquarie Ridge, at 50°38′S, 163°57′E (west of the Auckland Islands), in 682 m, and at 49°01′S, 164°30′E, in 741 m. *Metacrinus wyvilli*, also taken at the latter position, was previously only known from *Challenger* stations done as long ago as 1874, near the Kermadec Islands (Station 170a, 1152 m) and in the Philippines (Station 214, 914 m). *Comatulides dawsoni*, from 128 m on the Macquarie Ridge, has also been found on the Campbell Plateau, in depths from 435 to 1280 m, and *Florometra austini*, taken by the *Eltanin* off Auckland and Campbell Islands and near Cook Strait, was found on the Macquarie Ridge in 128 m, with a possible fragment at Macquarie Island in 155 m.

In the light of this new information, and the increase to 42 of the table of species recognised from the Macquarie Island area, table 1 sets out the new pattern of biogeographical affinities, which contrasts with tables published earlier (Dawson 1965, p.50; 1970, pp.134–135).

In 1965, the fauna of the island (excluding ophiuroids and crinoids, and having three less species of holothurian and only one species of echinoid) totalled 21 species; 52% also occurred in New Zealand (including species also in common with the Indo-West-Pacific or subantarctic); 16% were known only from other parts of the subantarctic; 15% were endemic. The fauna is now known to be twice as large, i.e. 42 species (now including the ophiuroids and crinoids). However, the occurrences in common beyond the Macquarie Island area still remain as before.

It is clear that the relationships lie more to the north than to the antarctic — only three species being shared with the New Zealand sector of the antarctic (Dawson 1970, table 1). The wide geographic spread of the species of crinoids, and their associated extreme depth range, indicate how such sessile forms may have used the existence of undersea topographic features to move into higher latitudes.

STYLASTERINA

The Stylasterina, one of the two orders of hydrocorals, with about 170 species, are found mostly in tropical and subtropical waters, but more than 20 species have been recorded from antarctic and subantarctic waters. These form a distinct zoogeographical unit, of which about 15 were alleged to be endemic (Boschma & Lowe 1969 — a cartographic summary, not fully documented).

A recently published report (Cairns 1983) of 29 species taken during *Eltanin* cruises recorded eight species from the Macquarie region, including three new species. One, *Cryptthelia fragilis* (described from the Pacific–Antarctic Ridge, at 52° 10′S, 142° 10′W), occurs on the Campbell Plateau as well as at *Eltanin* Station 1412 on the Macquarie Ridge, in 1647-1665 m. Another, *Errina (Inferiolabiata) fascicularis*, which occurs at the Antipodes Islands and eastwards to Tierra del Fuego and South Georgia, is described from *Eltanin* Station 1423, in 1574–1693 m, on the Hjort Seamount, some 190 km south of Macquarie Island. The third new species, *Errina (E.) cheilopora* was taken at *Eltanin* Station 1975, close to the island, in 443–549 m. In his zoogeographical analysis, Cairns regarded six of these eight species as endemic to the subantarctic region, restricted to the south of New Zealand, with one species also in the southern South American area (Magellanic subregion). The remaining two are widespread circum-antarctic and subantarctic. Regrettably, Cairns' analysis does not include NZOI stations from the Macquarie Island area, but his identifications of species from stations on the Campbell Plateau, north of New Zealand, demonstrate relationships with the Macquarie Island fauna.

SCLERACTINIA

The Scleractinia, the "true" or stony corals, include the reef-building corals of the tropics as well as the "simple" coral of cold and deep water. According to Squires (1969), the Scleractinia of the Southern Ocean, like the Stylasterina, form a distinctive biogeographical unit. He believed that the presence of nearly continuous, shallow, submarine ridges, linking Antarctica to New Zealand, allowed past invasion of the New Zealand region from the antarctic, leaving a number of relict species in the present-day fauna, but also that, more recently, faunal elements from New Zealand waters have moved southwards. An analysis of the New Zealand fauna (Squires & Keyes 1967) listed 25 species; almost half were considered to be endemic whereas the others displayed relationships to both the north and the south.

Later studies on corals throughout the world, by Cairns and others, have shown the widespread nature of many of the species, some being extremely cosmopolitan. Accordingly, the extent to which the term "endemic" may be applied to the 25 New Zealand species is likely to be considerably reduced in future assessments, and their relationship with the subantarctic fauna will need to be examined again.

Cairns (1982) has now published his account of the Southern Ocean corals taken by the *Eltanin* and by earlier NZOI cruises around Macquarie Island, dealing with 11 species from the Macquarie area, from the Hjort Seamount to the junction of the Macquarie Ridge with the New Zealand Plateau. Of these, eight are regarded as cosmopolitan, with their southern limits in the Macquarie region, two also occurred in New Zealand and South Australia and one was circum-subantarctic. Some of these species are wide-ranging. *Fungiacyathus fragilis*, taken in 1647–1665 m, at latitude 50° S on the Macquarie Ridge, occurs in the eastern Atlantic off Massachusetts, in the central Pacific off Hawaii, and off the west coast of the South Island of New Zealand. *Stenocyathus vermiformis*, known from the Atlantic Ocean, the Mediterranean Sea and the Indian Ocean, occurs on several parts of the Campbell Plateau as well as on the Macquarie Ridge. Yet another species is known, as *Enallopsammia marenzelleri*, from off the Azores, the Nicobar Islands and the Kei Islands in eastern Indonesia. Only two species were found close to Macquarie Island, one being *Flabellum knoxi*, a species abundant on the Campbell Plateau and on Chatham Rise, east of New Zealand.

This cosmopolitan element, so obvious in the deepwater corals from the Macquarie area, removes even further any distinctive "Kerguelenian" character of the fauna; it is notable that, according to Cairns, there are no records of Scleractinia from the Kerguelen Archipelago.

BRACHIOPODA

The brachiopods collected on *Eltanin* cruises were reported on by Foster (1974). Two species are common around Macquarie Island:

(1) *Magellania macquariensis*, described by Thompson (1918) from some 30 specimens in beach debris at Wireless Cove, collected by

Harold Hamilton during AAE. (Subsequently, at BANZARE Station 83, 629 specimens were taken, according to Cotton (1937), and NZOI collections hold it in abundance.) It was placed in the genus *Aerothyris* by Allan in 1939, and was described in some detail by Foster (1974), who extended its range to include the Antipodes Islands but also allied it to *M. kerguelensis*.

(2) *Gyrothyris mawsoni*, described by Thomson (1918) from a single specimen taken by AAE off the south end of Macquarie Island, is now known to be widespread across to the Campbell Plateau. Foster (1974) recognised three different subspecies from the *Eltanin* material: one in shallow water (79–124 m) off Macquarie Island, another in shallow water (86–192 m) on the southern edge of the Campbell Plateau, and the third in deeper water (333–540 m) in the same area. This provided another link across to the New Zealand area of the subantarctic but there are still some questions to resolve in delineating the exact population boundaries. A *Dimitry Mendeleev* station on 25 January 1976, in 300 m off Macquarie Island, yielded not only *Magellania* and *Gyrothyris* but also a species of *Neocrania* (K.R. Grange, pers. comm.).

KING CRABS

A spectacular member of the Macquarie benthic fauna is the large king crab *Lithodes murrayi*, an anomuran of the family Lithodidae. This species was originally described from *Challenger* Station 145A, off Prince Edward Island, in the southern Indian Ocean, and was first caught at Macquarie Island by Harold Hamilton in a fish trap (specimen in the Canterbury Museum). However, its presence was not officially recorded until Hale (1941) reported on specimens collected by BANZARE. From time to time, individuals or fragments are washed up on the shores of Macquarie Island, but it has been collected sufficiently often by NZOI, *Eltanin* or Soviet vessels (and more recently by ANARE) to indicate that it is reasonably abundant. With the current interest in the potential of Southern Ocean stocks of several species of king crab (Dawson & Yaldwyn 1985), including some which occur in New Zealand and southeastern Australian waters, its occurrence at Macquarie Island is important, and exploratory fishing, such as the French have done in the southern Indian Ocean, should be considered.

THE MOLLUSC FAUNA — A PARTIAL VIEW

Molluscan identifications are not yet complete, so no final overall biogeographic view is possible. The *Eltanin* material forms part of a wider Southern Ocean report by R.K. Dell, and B.A. Marshall is including some collections in his studies on trochid gastropods. The 47 NZOI benthic stations include 41 at which molluscs were collected (Amphineura — 26; Gastropoda — 39; Bivalvia — 33). BANZARE Station 83 was re-occupied on three separate occasions during NZOI cruises. Most of the 50 species listed by Pol (1957) have been identified in the NZOI collections, but some notable additions have been made. In the Trochidae, as well as further specimens of *Maurea megaloprepes*, a new species of *Calliostoma* was found on the Macquarie Ridge, in 124 m, at latitude 52°3′S, with a new genus and species of trochid, also known from Cook Strait, soon to be described from another station further north along the ridge at 49°39′S.

Cantrainea inexpectata Marshall, 1979, a species of the Turbinidae, has been identified from a station in 155 m, close to Macquarie Island; previously, it was known only from a single empty shell taken in 803–788 m on the southern Kermadec Ridge at 35°02′S, 179°15.8′E (Marshall 1979, p.551). *Xanthodaphne* and other turrids are also present in NZOI samples, as are other small species of the families Eulimidae and Volutomitridae. A species of *Socienna* (family Cerithiopsidae), closely resembling *S. aureola* originally taken at the Bounty Islands, is also present. This indicates the novelties that may be revealed when the smaller mollusc identifications are completed.

Fragments of a giant limid bivalve, *Acesta*, from south of Macquarie Island, provide a link with a distribution of this species, which occurs widely in bathyal depths throughout southern New Zealand and is allied to other forms in Patagonian waters, and in Indonesia, the Philippines, Japan and Norway.

The characteristic fan-shell from Macquarie Island is now regarded by Beu (1985) as representing a subspecies of the southern South American *Chlamys patagonica* (King & Broderip, 1831) and should be called *C. patagonica delicatula* (Hutton, 1873). As well as its palaeontological significance in the New Zealand region, it now provides a close biogeographic link with subantarctic South America. Beu has also noted that a fossil population from Tasmania, known as *Chlamys instar* Iredale, 1925, is synonymous with this subspecies, providing

a biological link between Tasmania and Macquarie Island.

Another new bivalve record is a member of the genus *Limopsis* closely related to a subantarctic species. A number of other New Zealand species have been identified from the most northerly part of the Macquarie Ridge.

The most interesting information derived so far from the NZOI mollusc collections in the Macquarie area is given in Beu's study (1978) of the cymatiid gastropod genera *Cymatona* and *Fusitriton*. *Cymatona kampyla tomlini* Powell was reported only at four shallow stations close to Macquarie Island, and Beu found it remarkable that a subspecies should have developed solely at Macquarie Island. *Cymatona kampyla kampyla* (Watson) was noted at 11 stations on the Macquarie Ridge, from about 190 km north of Macquarie Island to 46°35′S, thus extending into the New Zealand subantarctic. This subspecies also occurs in New Zealand and southeastern Australia. Although both *Cymatona* and *Fusitriton* have pelagic larvae which could be transported by the prevailing water movements from the west, Beu postulated that a gap in the Macquarie Ridge, about 80 km north of the island, could act as a partial barrier necessary for the development of a subspecies at Macquarie Island itself.

Cymatona is endemic to Australia and New Zealand and has a local fossil history. In contrast, the genus *Fusitriton* is wide-ranging and is represented by a series of southern races with no fossil record in New Zealand. Beu, therefore, suggested that *Fusitriton* had arrived in the New Zealand region during the Holocene or early Pleistocene, by way of the West Wind Drift (as proposed for echinoderms by Fell 1962); it had then ecologically displaced *Cymatona* into deeper water and a more limited range of sediments; thereafter rising sea temperatures and, presumably, decreased length of larval life had encouraged local speciation in *Fusitriton* populations. Whatever the full explanation on this isolated subspecies of *Cymatona* at Macquarie Island, one might look for parallels in the distribution of the echinoid *Pseudechinus novaezealandiae*, which also has pelagic larval dispersal between Macquarie Island and the New Zealand Plateau by way of the Macquarie Ridge (cf. Dawson 1965, fig. 3).

EPILOGUE

No new synthesis of the marine biogeography of Macquarie Island and its environs is attempted here. Despite the possibilities raised by the appearance of reports on the *Eltanin* and NZOI collections, the task is still fraught with difficulties, pitfalls and shortcomings.

Cumpston (1968, p.v) compared the subantarctic islands to stepping stones between the antarctic and more temperate lands. They offer only a precarious foothold and shelter to human kind or to those marine organisms that survive the rigours of transport by the West Wind Drift, "like Magellan's sailors" (Fell 1962, p.761). The marine habitats of Kerguelen are much more diverse (see Guille 1982) than those of Macquarie Island, although links with adjacent land masses are much more tenuous. The Macquarie Ridge can be used to explain the clear affinity of much of the deeper water fauna not only with New Zealand but with the Indo-West-Pacific and, indeed, in the case of Scleractinia, with the rest of the world.

It is difficult to make comparisons between faunal elements in the Southern Ocean, since the antarctic faunas may be derived from deep water forms in adjacent abyssal basins, reflecting the constraints of bottom topography, and subantarctic faunas may be shallow water or littoral in origin, reflecting the role of the West Wind Drift in the hydrological regime. A so-called "impoverished" fauna may, in fact, merely be evidence of inadequate sampling. Yet the knowledge of the benthic fauna of Macquarie Island, based on the contents of a single dredge haul in 89 m, has been little improved upon, except in number of individuals, by 47 subsequent occupations of benthic stations, ranging from the shore to nearly 2000 m.

Field workers are well aware of the mechanical problems of taking benthic samples in subantarctic or polar waters, with rugged sea bottom and inhospitable weather; also of the limitations that a dredge or trawl imposes on collecting representative samples of populations. An additional single specimen can topple a theory.

The distinctiveness of the Macquarie marine fauna is abundantly clear and the character of the Macquarie region should not be submerged by uniting it with a Kerguelenian Province (cf. Dell 1964, 1969). Whether or not we follow Kusakin (1968, p.355) in isolating this region as the "Macquarie Province", we must recognise that the island is merely the 400 m aerial projection of the submarine ridge of which it forms a structural part, and that the littoral fauna and the adjacent offshore

and deepwater animals are an integral part of its total character. The northern affinities of this fauna were developed, without much doubt, through the tectonically formed submarine topographic link.

Dell (1972, p.172) wrote of the great need for faunal monographs of all groups, prepared by experienced systematists and utilising the national collections already in existence. Also, it must be recognised that comprehensive studies of antarctic organisms are of basic importance, not only to a narrow range of specialists, but to all biologists concerned with biogeography.

In the intervening 15 years, nothing has altered, except that, with changing activity and human interest in the islands of the Southern Ocean, equal stress should be placed on urgent studies of the subantarctic also. Indeed, Dell believed that much more work should be done in investigating the life on the shelves surrounding the subantarctic islands, especially Marion and Prince Edward Islands, the Crozets, Kerguelen and Heard (Dell 1972, p.172). Through its tectonic history and its present-day geographic location, the Macquarie region — island and associated ridge — could well hold the key to many of the questions being asked by biologists and geologists alike on the origin and relationships of today's land masses and their associated offshore and deepwater faunas. It is important that investigation and study be planned for this region also.

REFERENCES

ADIE, R.J., 1963: Geological evidence on possible Antarctic land connections. *In* Gressit, J.L. (Ed.): *PACIFIC BASIN BIOGEOGRAPHY. A SYMPOSIUM, TENTH PACIFIC SCIENCE CONGRESS, HONOLULU, HAWAII 1961.* Bishop Museum Press, Honolulu: 455–463.

ALLAN, R.S., 1939: Studies on the Recent and Tertiary Brachiopoda of Australia and New Zealand. Part I. *Rec. Canterbury Mus.*, 4: 231–248.

BEU, A.G., 1978: The marine fauna of New Zealand. The molluscan genera *Cymatona* and *Fusitriton*. Gastropoda family Cymatiidae. *N.Z. oceanogr. Inst. Mem.*, 65: 1–43.

BEU, A.G., 1985: Pleistocene *Chlamys patagonica delicatula* (Bivalvia:Pectinidae) off southeastern Tasmania, and history of its species group in the Southern Ocean. *Spec. Pub., South Aust. Dep. Mines & Energy*, 5: 1–11.

BEU, A.G., GRANT-TAYLOR, T.L. & HORNIBROOK, N. de B., 1977: Nukumaruan records of the subantarctic scallop *Chlamys delicatula* and crab *Jacquinotia edwardsii* in central Hawkes Bay. *N.Z. J. Geol. Geophys.*, 20: 217–248.

BOSCHMA, H. & LOWE, T.P., 1969: Stylasterina. *Am. Geogr. Soc. Antarct. Map Folio Ser.*, 11: 15–18.

BRODIE, J.W., 1964: Bathymetry of the New Zealand Region. *N.Z. Dep. Sci. Ind. Res. Bull.*, 161: 1–56. [*NZOI Mem.*, 11.]

BRODIE, J.W. & DAWSON, E.W., 1965: Morphology of North Macquarie Ridge. *Nature*, 207: 844–845.

BURN, R., 1973: Opisthobranch molluscs from the Australian sub-Antarctic territories of Macquarie and Heard Islands. *Proc. R. Soc. Vict.*, 86: 39–46.

CAIRNS, S.D., 1982: Antarctic and Subantarctic Scleractinia. *In* Kornicker, L.S. (Ed.): *BIOLOGY OF THE ANTARCTIC SEAS XI. Antarct. Res. Ser. Am. Geophys. U.*, 34: 1–74.

CAIRNS, S.D., 1983: Antarctic and Subantarctic Stylasterina (Coelenterata : Hydrozoa). *In* Kornicker, L.S. (Ed.): *BIOLOGY OF THE ANTARCTIC SEAS XIII. Antarct. Res. Ser. Am. Geophys. U.*, 38: 61–164.

CLARK, A.M., 1962: Asteroidea. *BANZARE Rep.*, Ser. B(9): 1–104.

COTTON, B.C., 1937: Brachiopoda. *BANZARE Rep.*, Ser. B(4), 1: 20–22.

CULLEN, D.J., 1970a: Tectonic map of the South-west Pacific. *NZOI Chart*, Misc. Ser., 1:10,000,000.

CULLEN, D.J., 1970b: Macquarie Island. Provisional bathymetry. *NZOI Chart*, Island Ser., 1:200,000.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1), Narrative. Antarctic Division, Department of External Affairs, Melbourne.

DAWSON, E.W., 1963: Oceanography in the Sub-Antarctic. *Antarctic*, 3(7): 312–314.

DAWSON, E.W., 1964: Antarctic oceanography. *Antarctic*, 3(10): 430–432.

DAWSON, E.W., 1965: Oceanography and marine zoology of the New Zealand Subantarctic. *Proc. N.Z. Ecol. Soc.*, 12: 44–57.

DAWSON, E.W., 1968: Problems and progress in the zoogeography of a sector of the Southern Ocean; an excursion with the Echinodermata into New Zealand-Antarctic relationships. *In* Currie, R.L. (Ed.): *SYMPOSIUM ON ANTARCTIC OCEANOGRAPHY, SANTIAGO, CHILE, 13–16 SEPTEMBER 1966.* Scott Polar Research Institute for SCAR, Cambridge: 124–125.

DAWSON, E.W., 1970: Faunal relationships between the New Zealand Plateau and the New Zealand sector of Antarctica based upon echinoderm distribution. *N.Z. J. mar. Freshwat. Res.*, 4: 126–140.

DAWSON, E.W., 1982: [The bathyal marine fauna of the New Zealand Exclusive Economic Zone.] *In* Kussakin, O.G. & Kafanov, A.I. (Eds): [*Fauna and Hydrology of the Shelf Zones of the Pacific Ocean.*] *Proc. XIV Pacif. Sci. Congr.*, 4: 43–60 [in Russian with English summary].

DAWSON, E.W. & YALDWYN, J.C., 1985: King crabs of the world or the world of King crabs: an

overview of identity and distribution — with illustrated diagnostic keys to the genera of the Lithodidae and to the species of *Lithodes*. *In* Melteff, B.R. (Ed.): *Proceedings of the International King Crab Symposium, Anchorage, Alaska, USA, January 1985. Univ. Alaska, Alaska Sea Grant Rep.*, 85-12: 69-106, illus.

DELL, R.K., 1964: Marine Mollusca from Macquarie and Heard Islands. *Rec. Dom. Mus., Wellington*, 4: 267-301.

DELL, R.K., 1969: Benthic Molluscs. *Am. Geogr. Soc. Antarct. Map Folio Ser.*, 11: 25-26.

DELL, R.K., 1972: Antarctic benthos. *In* Russell, F.S. & Yonge, M. (Eds): *ADVANCES IN MARINE BIOLOGY*, vol. 10. Academic Press, London and New York: 1-216.

DENDY, A., 1896: Observations on the holothurians of New Zealand; with descriptions of four new species, and an appendix on the development of the wheels in *Chirodota*. *J. Linn. Soc., Zool.*, XXVI: 22-50.

FELL, H.B., 1962: West-wind-drift dispersal of echinoderms in the Southern Hemisphere. *Nature*, 193: 759-761.

FOSTER, M.W., 1974: Recent Antarctic and Subantarctic brachiopods. *Antarct. Res. Ser. Am. Geophys. U.*, 21: xii, 1-190.

GRIFFITHS, J.R. & VARNE, R.,1972: Evolution of the Tasman Sea, Macquarie Ridge and Alpine Fault. *Nat. Phys. Sci.*, 235: 83-86.

GUILLE, A., 1982: A new genus and species of ophiacanthid brittlestar (Echinodermata: Ophiuroidea) from the Kerguelen Islands, with new taxonomic, biogeographic and quantitative data on the echinoderm fauna. *In* Rowe, F.W.E. (Ed.): *Papers from the Echinoderm Conference, The Australian Museum Sydney, Sydney, 1978. Aust. Mus. Mem.*, 16: 67-87.

GUR'YANOVA, E.F., 1964: Amphipod fauna (Amphipoda) of Macquarie Island. *Sov. Antarct. Exped. Bull.*, 1: 128-129 [Elsevier translation of 1958 original].

HALE, H.M., 1941: Decapod Crustacea. *BANZARE Rep.*, Ser. B(4): 257-286.

HAMILTON, A., 1895: Notes on a visit to Macquarie Island. *Trans. Proc. N.Z. Inst.*, XXVII: 559-579.

HAYES, D.E. (Ed.), 1972: Antarctic Oceanology II. The Australian-New Zealand sector. *Antarct. Res. Ser. Am. Geophys. Un.*, 19: xii, 1-364.

HEDGPETH, J.W., 1969: Introduction to Antarctic zoogeography. *Am. Geogr. Soc. Antarct. Map Folio Ser.*, 11: 1-9.

HEDLEY, C., 1916: Mollusca. *AAE Sci. Rep.*, Ser.C(4): 1-80.

HOUTMAN, Th.J., 1967: Water masses and fronts in the Southern Ocean south of New Zealand. *Bull. N.Z. Dep. Sci. Ind. Res.*, 174: 1-40. [*NZOI Mem.* 36.]

HUTTON, F.W., 1873: *CATALOGUE OF THE TERTIARY MOLLUSCA AND ECHINODERMATA OF NEW ZEALAND IN THE COLLECTION OF THE COLONIAL MUSEUM*. Government Printer, Wellington.

IREDALE, T., 1925: Mollusca from the continental shelf of eastern Australia. *Rec. Aust. Mus.*, 14: 243-270.

KENNY, R. & HAYSOM, N., 1962: Ecology of rocky shore organisms at Macquarie Island. *Pacif. Sci.*, XVI: 245-263.

KING, P.P. & BRODERIP, W.J., 1831: Description of the Cirrhipedia, Conchifera, and Mollusca in a collection formed by the officers of H.M.S. "Adventure" and "Beagle" employed between the years 1826 and 1830 in surveying the southern coasts of South America, including the Straits of Magelhaens and the coast of Tierra del Fuego. *Zool. J. (Lond.)*, 5: 332-349.

KOEHLER, R., 1920: Echinodermata Asteroidea. *AAE Sci. Rep.*, Ser.C(8), 1: 1-308.

KOEHLER, R., 1926: Echinodermata Echinoidea. *AAE Sci. Rep.*, Ser.C(8), 3: 1-134.

KUSAKIN, O.G., 1968: Fauna of Isopoda and Tanaidacea in the coastal zones of the Antarctic and Subantarctic waters. *Biol. Rep. Sov. Antarct. Exped. (1955-1958)*, 3: 220-389 [translated from *Issled. fauny morei* IV (XII), 1967].

McKNIGHT, D.G., 1984: Echinoderms from Macquarie Island and the Macquarie Ridge. *NZOI Rec.*, 4: 139-147.

MADSEN, F.J., 1967: Ophiuroidea. *BANZARE Rep.*, Ser. B(9), 3: 121-148.

MARSHALL, B.A., 1979: The Trochidae and Turbinidae of the Kermadec Ridge (Mollusca:Gastropoda). *N.Z. J. Zool.*, 6: 521-552.

MERILEES, W. & BURN, R., 1969: *Archidoris kerguelenensis* Bergh, the first record of a nudibranch from Macquarie Island. *Vict. Nat.*, 86: 137-138.

NATURE, 1968: News and Views. Why so long delayed? *Nature*, 220: 855.

PAWSON, D.L., 1962: A new sea cucumber from Macquarie Island. *Trans. R. Soc. N.Z., Zool.*, 2: 47-48.

PAWSON, D.L., 1968a: Some holothurians from Macquarie Island. *Trans. R. Soc. N.Z., Zool.*, 10: 141-150.

PAWSON, D.L., 1968b: The echinozoan fauna of the New Zealand Subantarctic Islands, Macquarie Island and the Chatham Rise. *Bull. N.Z. Dep. Sci. Ind. Res.*, 187: 1-36 [NZOI Mem. 42].

PAWSON, D.L., 1969: Holothuroidea. *Am. Geogr. Soc. Antarct. Map Folio Ser.*, 11: 36-38.

PETROVSKAYA, M.V., 1970: Bibliography of biological researches of the Soviet-Antarctic Expedition. *Biol. Rep. Sov. Antarct. Exped.*, 4: 258-292 [translated from *Issled. fauny morei* VI(XIV), 1968].

POWELL, A.W.B., 1955: Mollusca of the southern islands of New Zealand. Cape Expedition — Scientific Results of the New Zealand Sub-

Antarctic Expedition, 1941–43. *Bull. Cape Exped. Ser.*, 15: 1–152.

POWELL, A.W.B., 1957: Mollusca of Kerguelen and Macquarie islands. *BANZARE Rep.*, Ser. B(6): 107–150.

POWELL, A.W.B., 1979: *NEW ZEALAND MOLLUSCA*. Collins, Auckland.

PRICE, A.G., 1963: Geographical report based on the Mawson papers. *BANZARE Rep.*, Ser. A(1): xviii, 1–242.

SCOTT, J.H., 1883: Macquarie Island. *Trans. Proc. N.Z. Inst.*, XV: 484–493.

SELKIRK, D.R., SELKIRK, P.M. & SEPPELT, R.D., 1986: An annotated bibliography of Macquarie Island. *ANARE Res. Notes*, 38: iv, 1–134.

SPEEL, J.A. & DEARBORN, J.H., 1983: Comatulid crinoids from R/V "Eltanin" cruises in the Southern Ocean. *In* Kornicker, L.S. (Ed.): *BIOLOGY OF THE ANTARCTIC SEAS XIII. Antarct. Res. Ser. Am. Geophys. U.*, 38: 1–60.

SQUIRES, D.F., 1969: Scleractinia. *Am. Geogr. Soc. Antarct. Map Folio Ser.*, 11: 15–18.

SQUIRES, D.F. & KEYES, I.W., 1967: The marine fauna of New Zealand: Scleractinian corals. *Bull. N.Z. Dep. Sci. Ind. Res.*, 185: 1–46 [*NZOI Mem.* 43].

SUMMERHAYES, C.P., 1967: Macquarie bathymetry. *NZOI Chart*, Oceanic Ser., 1:1,000,000.

SUMMERHAYES, C.P., 1969: Marine geology of the New Zealand subantarctic sea floor. *Bull. N.Z. Dep. Sci. Ind. Res.*, 190: 1–94 [*NZOI Mem.* 50].

SUTER, H., 1913: *MANUAL OF THE NEW ZEALAND MOLLUSCA, WITH ATLAS OF PLATES* [1915]. Government Printer, Wellington.

THOMSON, J.A., 1918: Brachiopoda. *AAE Sci. Rep.*, Ser. C(4), 3: 1–76.

TOMLIN, J.R. Le B., 1948: The Mollusca of Macquarie Island. Gastropods and bivalves. *BANZARE Rep.*, Ser. B, 5: 221–232.

UBALDI, R., 1985: Il genre *Nacella* Schumacher, 1817. Part III. The subantarctic species of genus *Patinigera* Dall, 1905. *Argonauta*, 1(4–5): 77–90.

WANOA, R.J. & LEWIS, K.B., 1972: Gazetteer of seafloor features in the New Zealand region. *NZOI Rec.*, 1(5): 67–106.

WILLIAMSON, P., 1974: Recent studies of Macquarie Island and the Macquarie Ridge Complex. *Bull. Aust. Soc. Explor. Geophys.*, 5: 19–22.

(accepted 7 September 1987)

APPENDIX

Checklist of marine fauna of Macquarie Island and Macquarie Ridge

Stylasterina, Scleractinia, Mollusca, Brachiopoda, Echinodermata [all species listed in alphabetical order, not in taxonomic sequence].

STYLASTERINA

[see Cairns 1983]

Allopora eguchii Boschma, 1966
Calyptopora reticulata Boschma, 1968
Conopora pauciseptata Broch, 1951
Crypthelia fragilis Cairns, 1983
Errina (Errina) cheilopora Cairns, 1983
E. (Errina) gracilis von Marenzeller, 1903
E. (Inferiolabiata) fascicularis Cairns, 1983
Lepidopora sarmentosa Boschma, 1968

SCLERACTINIA

[see Cairns 1982]

Aulacyathus recidivus (Dennant, 1906)
Desmophyllum cristagalli Milne Edwards & Haime, 1848
Enallopsammia sp. cf. *E. marenzelleri Zibrowius, 1973*
E. rostrata (Pourtales, 1878)
Flabellum apertum Moseley, 1876
F. knoxi Ralph & Squires, 1962
Fungiacyathus fragilis Sars, 1872
Lophelia prolifera (Pallas, 1766)
Madrepora oculata Linnaeus, 1758
Solenosmilia variabilis Duncan, 1873
Stenocyathus vermiformis (Pourtales, 1868)

MOLLUSCA

[see Powell 1979; includes also some interim NZOI determinations, marked *, as well as Eltanin identifications kindly made available by Dr R.K. Dell (pers. comm., May 1987), marked [E]]

Bivalvia

Acesta sp.*
Chlamys patagonica delicatula (Hutton, 1873) [E]
Gaimardia trapesina coccinea Hedley, 1916
Hiatella arctica (Linnaeus, 1767)
Kidderia bicolor (Martens, 1835)
K. oblonga (Smith, 1899)
K. subquadrata (Pelseneer, 1903)
Lasaea rubra rossiana Finlay, 1928
Limatula pygmaea (Philippi, 1845)
Limopsis sp.*
Modiolus areolatus (Gould, 1850)*
Monia sp.*
Mysella charcoti (Lamy, 1906)
M. macquariensis (Hedley, 1916)
Neolepton powelli Dell, 1964
Philobrya hamiltoni (Hedley, 1916)
Pleuromeris sp.*
Pronucula mesembrina (Hedley, 1916)
Tawera mawsoni (Hedley, 1916) [E]
Thracia sp.*

Gastropoda (excluding pteropods)

[see also Burn 1973, Merilees & Burn 1969]

Actinoleuca campbelli macquariensis (Hedley, 1916)
Admete harpovoluta (Powell, 1957)
Archidoris kerguelenensis (Berg, 1884)
Brookula sp.
Calliostoma n.sp. (Marshall MS)
Cantharidus (Plumbelenchus) capillaceus coruscans (Philippi, 1848) [E]
M. macphersonae (Dell, 1964)
Margarella macquariensis (Hedley, 1916) [E]
Maurea megaloprepes (Tomlin, 1948) [E]
Maurea sp.*
Melanella sp. cf. *M. laseroni* Hedley, 1948
Nacella (Patinigera) macquariensis (Finlay, 1927)
N. (Nacella) kerguelenensis (Smith, 1877)

Gastropoda (cont.)

Cantrainea inexpectata (Marshall, 1979)*
Cymatona kampyla tomlini (Powell, 1955) [Macquarie Island] [E]
C. kampyla kampyla (Watson, 1885) [Macquarie Ridge]*
Eatoniella sp. cf. *E. kerguelenensis kerguelenensis* (Smith, 1875)
Emarginula sp.*
Eumetula macquariensis (Tomlin, 1948)
Evalea sp.
Falsilunatia pisum (Hedley, 1916) [E]
F. sp. [E]
Fusitriton cancellatus laudandus (Finlay, 1927)*
Kerguelenella lateralis (Gould, 1846)
Laevilitorina caliginosa (Gould, 1849)
Lamellaria sp. cf. *L. conica* (Smith, 1902)
Macquariella hamiltoni (Smith, 1898)
Notoacmea pileopsis sturnus (Hombron & Jacquinot, 1841)
Ovirissoa ainsworthi (Hedley, 1966)
O. nivosa Powell, 1957
Pareuthria sp. cf. *P. valdiviae* (Thiele, 1925)
Prosipho sp. cf. *P. certus* Thiele, 1912
P. tomlini Powell, 1957
Puncturella pseudanaloga Powell, 1957
Sinezona subantarctica (Hedley, 1916)
Socienna sp.*
Subonoba sp.
Trinchesia macquariensis Burn, 1973
Trophon macquariensis Powell, 1957 [E]
T. mawsoni Powell, 1957 [E]
Turbonilla (Chemnitzia) lamyi Hedley, 1916
Xanthodaphne sp.*

Amphineura

Hemiarthrum setulosum (Dall, 1876)
Ischnochiton mawsoni Cotton, 1937
Plaxiphora aurata campbelli Filhol, 1880
Terenochiton fairchildi Iredale & Hull, 1929

BRACHIOPODA

[see Thompson 1918, Foster 1974]

Gyrothyris mawsoni mawsoni Thomson, 1918
G. mawsoni antipodensis Foster, 1974
Magellania macquariensis Thompson, 1918
Neocrania sp. ["Dimitry Mendeleev"]

ECHINODERMATA

[see Speel & Dearborn 1983, McKnight 1984]

Comatulides dawsoni McKnight, 1977
Daidalometra arachnoides (A.H. Clark, 1909)
Florometra austini A.M. Clark, 1967
Glyptometra inaequalis (Carpenter, 1888)
Metacrinus wyvilli Carpenter, 1888
Ptilocrinus sp. McKnight, 1984
Antedonid B Speel & Dearborn, 1983

Asteroidea

[see Koehler 1920, Clark 1962, McKnight 1984]

Anasterias directa (Koehler, 1920)
A. mawsoni (Koehler, 1920)
A. sphoerulata (Koehler, 1920)
Ceramaster lennoxkingi McKnight, 1973
Cycethra macquariensis Koehler, 1920
Henricia aucklandiae Mortensen, 1925
H. lukinsii (Farquhar, 1895)
H. obesa (Sladen, 1889)
Odontaster aucklandensis McKnight, 1973
Porania antarctica antarctica Smith, 1876
Pseudarchaster sp. McKnight 1984
Pteraster (Apterodon) stellifer stellifer Sladen, 1889
Sclerasterias mollis Hutton, 1872
Smilasterias irregularis H.L. Clark, 1928

Echinoidea

[see Koehler 1926, McKnight 1984]

Goniocidaris umbraculum Hutton, 1878
Pseudechinus novaezealandiae (Mortensen, 1921)

Ophiuroidea

[see Madsen 1967, McKnight 1984]

Amphipholis squamata (della Chiaje, 1828)
Amphiura angularis (Lyman, 1879)
A. magellanica (Ljungman, 1866)
Homalophiura inornata (Lyman, 1878)
Ophiacantha pentagona Koehler, 1922
O. sollicita Koehler, 1922
Ophiactis hirta Lyman, 1882
Ophiomitrella conferta (Koehler, 1922)
Ophiomyxa sp. McKnight, 1984
Ophiopyren regularis Koehler, 1901
Ophiuroglypha irrorata (Lyman, 1878)

Holothuroidea

[see Dendy 1896, Pawson 1962, 1968a,b, McKnight 1984]

Ocnus calcarea (Dendy, 1896)
Pseudocnus laevigatus (Verrill, 1876)
P. leoninoides (Mortensen, 1925)
Pseudopsolus macquariensis (Dendy, 1896)
Psolus antarcticus (Philippi, 1857)
Trachythyone macphersonae Pawson, 1962
Trochodota dendyi Mortensen, 1925
T. dunedinensis (Parker, 1881)
T. sp. Pawson, 1968a

THE NEARSHORE FISHES OF MACQUARIE ISLAND

by R. Williams

(with four tables and one text-figure)

WILLIAMS, R., 1988 (viii): The nearshore fishes of Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 122(1): 233–245. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–7403. Antarctic Division, Channel Highway, Kingston, Tasmania, Australia 7150.

The fish fauna of Macquarie Island is basically subantarctic, but the island's position near the Antarctic Convergence is highlighted by the presence of both pelagic and benthic antarctic forms on the one hand and temperate Australasian forms on the other.

Key Words: Macquarie Island, fish fauna, benthic species, pelagic species, nearshore fishes.

INTRODUCTION

Macquarie Island is one of a group of subantarctic islands in the vicinity of the Antarctic Convergence, which extends from South Georgia in the west to the island groups south of New Zealand in the east (fig. 1). The fish faunas at these island groups have obvious affinities, with the majority of benthic species belonging to the typically antarctic suborder Notothenioidei (DeWitt 1971), even though they are subjected to a wide range of oceanographic conditions. These range from truly antarctic at South Georgia, Bouvet and Heard Islands, which are south of the Antarctic Convergence, to the much more temperate conditions at Marion Island, Prince Edward Island and the southern New Zealand islands, which lie nearer to the Subtropical Convergence.

Macquarie Island occupies a similar position to the Iles Kerguelen with respect to the Antarctic Convergence, lying just north of it at 54°30'S, 159°E. This is reflected in the monthly mean sea temperatures, which range from 4.3°C (July) to 6.8°C (January) (Simpson 1976), although Kenny & Haysom (1962) report monthly mean temperatures as low as 2.8°C for July, indicating that the Convergence reaches at least as far north as the island on occasions. This is confirmed by recent satellite images of sea surface temperatures, which show that the Antarctic Convergence passes within about 40 km of the southeast corner of the island.

The island is the only exposed portion of the Macquarie Ridge, which stretches southsouthwest from New Zealand to near the Antarctic Continent. Hence the "shelf" around the island is extremely narrow and isolated from other land masses. The total area of water less than 1000 m deep on the ridge (as measured from Summerhayes 1967) is 1023 square nautical miles. The minimum distance of the 1000 m isobath from the island is 1.3 nautical miles off the southeast corner, and the width of the shelf shallower than 1000 m averages about 10 nautical miles (measured from Cullen 1970).

The fish fauna of Macquarie Island is poorly known compared to that at other subantarctic islands. Hitherto only eight benthic and four pelagic species were known, whereas Iles Kerguelen has 42 benthic species (Hureau 1979, Duhamel & Hureau 1982), and South Georgia has 33 benthic species (DeWitt 1971). Six species of benthic fish and four pelagic species were collected by the Australasian Antarctic Expedition (AAE) of 1911–14 (Waite 1916, Whitley 1931, 1939, 1941). The British, Australian and New Zealand Antarctic Research Expedition (BANZARE) only collected two previously known species (Norman 1937), and Nelson (1977, 1982) reported two new benthic species collected by the USCGS *Eltanin*. Otherwise the only references to Macquarie Island fish are in works dealing with antarctic zoogeography (Norman 1938, Andriashev 1965, DeWitt 1971), and in a revision of some Nototheniidae (DeWitt 1970), an analysis of the commercial prospects of the Island (Williams 1983), a brief synopsis of the fish fauna (Williams 1984), and a report of a mass stranding of myctophids (Merilees 1984).

During December 1986, a brief survey of both benthic and pelagic fish was conducted in order to make good this deficiency in our knowledge of the marine fauna of this isolated area of shallow water, situated in the transition zone between antarctic and subantarctic waters. In addition to reporting on these recently acquired data, this paper will also bring together all known records of

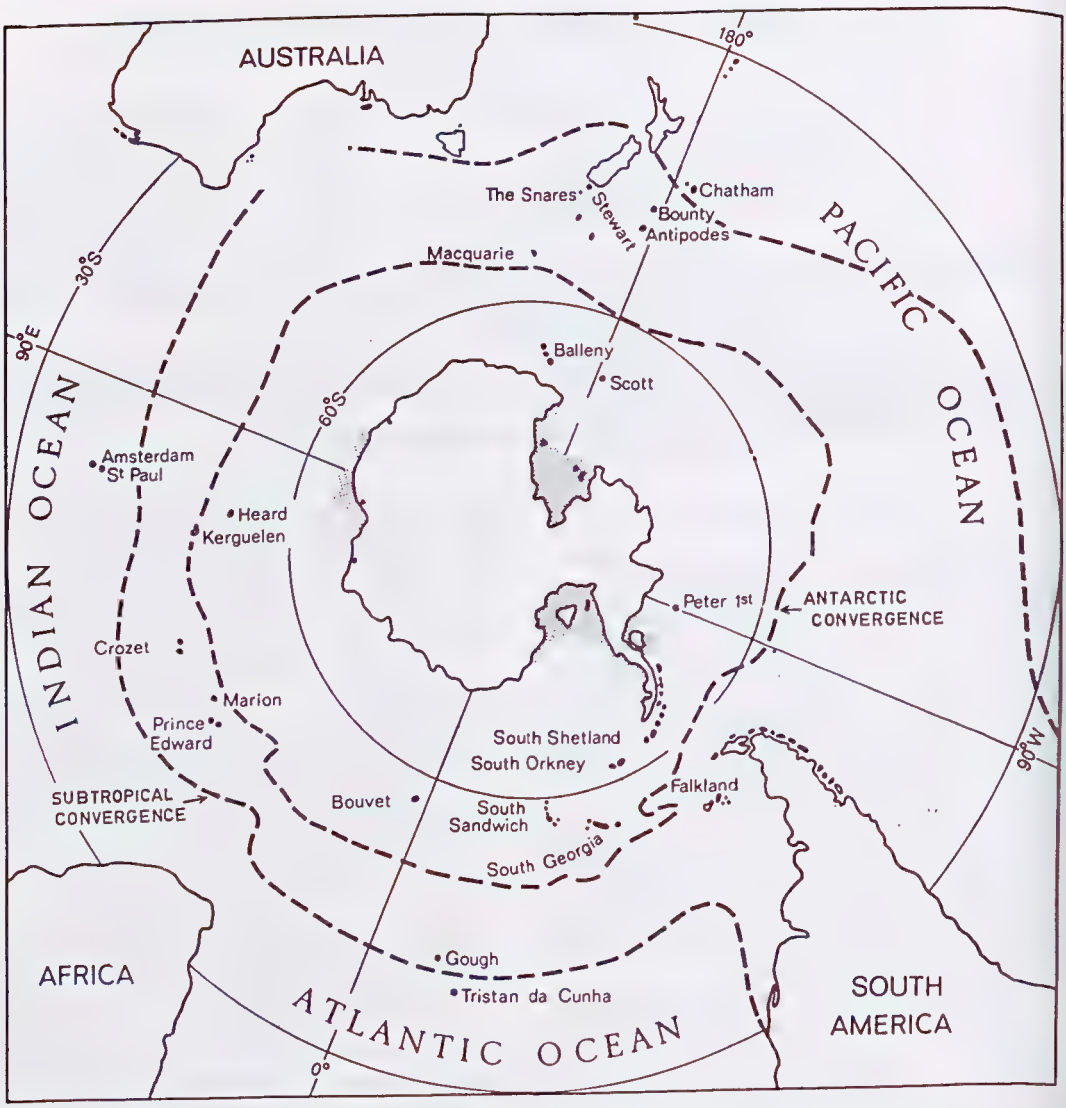

FIG. 1 — Positions of the subantarctic islands and southern continents. The Antarctic Convergence and the Subtropical Convergence are indicated.

fish from the area and discuss the zoogeographical relationships of the fauna.

MATERIALS AND METHODS

Information and/or specimens were obtained from the following sources:

(1) References in the literature to earlier collections. These were principally AAE, which used baited lines and traps and collected stranded specimens from the beaches; BANZARE, which used dredges at two stations off the northwest and southeast coasts; the *Eltanin* collection from two trawls east of North Head; and collections made by the Australian Museum by diving (Lowry *et al.* 1978).

(2) Specimens examined from collections held by the Tasmanian Museum, Museum of Victoria, Australian Museum (Sydney) (mostly from the diving survey of 1977) and CSIRO Division of Fisheries Research, Hobart. Additional specimens have been obtained since 1975 by expeditioners at

the island, either by angling from the shore or collecting specimens stranded on the beaches.
(3) Material from recent studies of bird diet, especially gentoo penguins (*Pygoscelis papua*) and king penguins (*Aptenodytes patagonicus*) (G. Robertson, pers. comm., and Hindell, in press).
(4) A survey, between 6 and 10 December 1986, for both benthic and pelagic fish in the vicinity of the island. A 3 m wide beam trawl, with a mesh size of 50 mm in the body and 25 mm in the cod end, was used to sample benthic fish from nine stations at depths between 40 and 375 m on the east and west coasts of the island. Pelagic fish were captured in five hauls of a rectangular midwater trawl (RMT), with an 8 m^2 mouth area and mesh size of 4.5 mm. Hauls were either horizontal, at 50 m depth, or oblique, between 250 and 500 m, over bottom depths of 600–2200 m on the east and north coasts. Table 1 gives details of all benthic and pelagic hauls during this survey.

TABLE 1

Summary of Benthic and Pelagic Net Hauls during the 1986 Survey

Haul	Date	Local time	Lat.	Long.	Depth range (m)	Bottom depth (m)	Locality
BENTHIC HAULS							
1	6 Dec 86	2057	54°44.0	158°51.4	35–41		0.6–0.45 miles off Lusitania Bay
2	6 Dec 86	2159	54°43.5	158°53.1	100–105		0.9–0.65 miles off Lusitania Bay
3	8 Dec 86	2212	54°33.4	158°56.9	108–135		1.6–0.95 miles off Nuggets
4	9 Dec 86	0154	54°45.0	158°52.3	65–90		0.7–0.5 miles off Lusitania Bay
5	9 Dec 86	0300	54°44.2	158°52.3	57–70		0.7 miles off Lusitania Bay
6	9 Dec 86	0348	54°43.4	158°52.1	25–29		0.5 miles off Lusitania Bay
7	10 Dec 86	0101	54°31.4	158°50.8	150–200		1.3 miles off Eagle Point
8	10 Dec 86	0211	54°29.7	158°51.2	330–450		1.7 miles off Handspike Point
9	10 Dec 86	0640	54°23.6	158°59.3	100		2.9 miles NW of Judge & Clerk Rocks
RECTANGULAR MIDWATER TRAWL HAULS							
1	9 Dec 86	2139	54°30.6	159°00.2	100-160	1200-650	2.4 miles off Nuggets
2	9 Dec 86	2248	54°30.8	159°00.0	50	1130-600	2.2 miles off Nuggets
3	9 Dec 86	2355	54°29.6	159°02.5	250–500	>2000	3.4 miles E of North Head
4	10 Dec 86	2150	54°19.1	158°53.7	50	1150-1500	5.7 miles WNW of Judge & Clerk Rocks
5	10 Dec 86	2240	54°18.5	158°51.9	250-500	1500-2200	7.3 miles WNW of Judge & Clerk Rocks

ANNOTATED CHECKLIST OF FISHES — BENTHIC SPECIES

The following benthic species are now known from Macquarie Island.

Family Squalidae

***Somniosus microcephalus* Bloch & Schneider**

One specimen is known from the island, found on the beach in 1913 and reported by Waite (1916) as *?Somniosus* sp. Only the teeth and a portion of the skin were kept, together with a sketch of the whole animal, so that positive identification is not now possible. Whitley (1939) proposed a new species, *S. antarcticus*, for this specimen, but the presence of *S. microcephalus* around Iles Kerguelen (Duhamel & Hureau 1982) and the absence of an adequate description of the Macquarie Island specimen suggests its retention as *S. microcephalus*. This species has a worldwide distribution, extending to northern polar waters, but this is the most southerly record of this genus.

Family Muraenolepididae

***Muraenolepis marmoratus* Gunther**

Two specimens are recorded from the island. One (CSIRO CA2988, 303 mm standard length (SL)) was caught in a fish trap in Garden Cove at 10 m depth in 1951. The other (Tasmanian Museum D748, 346 mm SL) was also caught in a fish trap in Garden Cove in 1966.

The taxonomy of *Muraenolepis* is not well known. Of the four species so far described (Tomo & Hureau 1985), these specimens most closely fit *M. microps*, in that the mental barbel and dorsal filament are 1–2 times the eye diameter, and the dorsal profile of the head is curved. Other characters, however, are not consistent with this species. The lateral line, which is very difficult to see, appears to extend beyond the anus, and the head is relatively large (4.68 and 4.90 in SL). The number of vertebrae (68 and 69) in the second dorsal (141 and 137) and anal fins (108 and 99), and the upper jaw length in SL (9.4% and 9.9%) agree closely with a new description of *M. marmoratus* (O. Gon, pers. comm.). Only the mental barbel being slightly longer than the eye diameter disagrees with this new diagnosis, and provisionally these specimens are placed in *M. marmoratus*.

M. marmoratus is well known from the Crozet, Kerguelen and Heard Islands (Tomo & Hureau 1985).

Family Macrorhamphosidae

***Centriscops cf. humerosus* (Richardson)**

One specimen (National Museum of Canada NMC78-2, 90 mm SL) was found on Gadgets Beach in March 1967. Morphometric and meristic characters are consistent with *C. humerosus*, but the colouration does not match, this specimen being without the prominent black bands or spots described by Mohr (1937). Perhaps the uniform silver colouration below the lateral line and brown above it is the juvenile pattern. Mohr (1937) gives the distribution of *Centriscops* spp. as temperate waters of South America, Australia and New Zealand, while May & Maxwell (1986) report it from the southern coast of Australia between Western Australia and New South Wales.

Family Congiopodidae

***Zanclorhynchus spinifer* (Gunther)**

One of the commonest fish at the island, this species has been reported in almost every account of the fish fauna, including those of AAE (Waite 1916), BANZARE (Norman 1937), Slack-Smith (1962) and Lowry *et al.* (1978). It is most common in waters less than 100 m deep and is often seen in the kelp zone (Waite 1916) and in wave-generated troughs on sandy bottoms (Lowry *et al.* 1978). It was the second most abundant fish in the trawl survey with 277 specimens (24.8% of total) being caught in depths from 27–120 m, and it comprises 32.5% by number of the catch from depths less than 100 m.

This species is known from all the subantarctic islands of the Indian Ocean, where it is usually abundant (Hureau 1985a).

Family Psychrolutidae

***"Neophrynichthys" magnicirrus* Nelson**

This species was first described by Nelson (1977) from four specimens caught in 88–101 m depth off the northeast coast of the island. Two further specimens were caught in hauls 4 and 5 in 57–90 m depth off Lusitania Bay in the southeast of the island during the 1986 trawling survey. The species is endemic to Macquarie Island and, although its generic position is unclear, it appears most closely related to *"N." angustus* from New Zealand and its southern islands, and to *N. latus* from New Zealand (Nelson 1982).

***Ebinania macquariensis* Nelson**

This is another psychrolutid endemic to Macquarie Island, the only record being the two specimens trawled from 494–714 m off the northeast coast in 1965 on which Nelson (1982) based his original description. The genus is widespread in the Pacific Ocean, with members recorded south of Pitcairn Island and off Japan (Nelson 1982) and off South Australia (May & Maxwell 1986).

Family Nototheniidae

***Dissostichus eleginoides* Smitt**

Three specimens were caught from hauls 3 and 4, at 65–90 m and 108–135 m depth off the east coast during the 1986 survey. They were sub-adult fish with standard lengths 315–517 mm; this record represents an extension of their range eastwards from Iles Kerguelen. They are common off Patagonia, the Antarctic Peninsula and all subantarctic islands from the Scotia Arc to Kerguelen, and are exploited commercially in several areas (Hureau 1985b).

***Notothenia rossii rossii* Richardson**

Only a few specimens of this species have been encountered at Macquarie Island, although it is very common inshore at the other subantarctic islands in the Indian sector. Waite (1916) reported only two specimens (as *N. coriiceps* var. *macquariensis*) from AAE, despite two years' fishing with lines and traps, and subsequently only seven specimens (300–533 mm SL) have been collected from beach strandings or angling. None was caught during the trawling survey. After a pelagic larval phase, juvenile *N. rossii* inhabit the coastal zone limited by the outer edge of the kelp belts, and at the onset of sexual maturity (at 430–480 mm SL) the fish move to the open shelf area (Duhamel 1982). The observed size range caught from the shore thus fits with the juvenile stage, but if the fish were common at Macquarie Island, as they are at the other subantarctic islands, where they are commercially exploited, the trawl survey should have produced some adults.

***Notothenia squamifrons* Gunther**

This species was not identified positively from Macquarie Island until the 1986 trawling survey, although some material from bird stomachs and other damaged specimens indicated that it might be present. *N. squamifrons* was the commonest species in the trawling survey, comprising 72% of the catch (810 specimens) from depths between 57–400 m. No *N. squamifrons* were caught in the shallower trawls (hauls 1 and 6). Their standard length ranged from 31–187 mm, with major peaks in the length frequency at 37 and 78 mm, and minor peaks at 103, 120 and 145 mm. These peaks are consistent with those for the first five year classes given by Duhamel & Ozouf-Costaz (1985) for Crozet Islands fish, if allowance is made for the differing month of sampling.

This fish is widespread and common around all the subantarctic islands, from the Scotia Arc and South Georgia to Kerguelen and Heard Islands, on shelves and upper slopes to 570 m depth. It is fished commercially at South Georgia and Kerguelen (Hureau 1985b).

***Paranotothenia magellanica* (Forster)**

The commonest inshore fish at Macquarie Island, this species has been reported as abundant in the kelp zone (as *Notothenia macrocephala*) in nearly all accounts of the island's fish (Waite 1916, Slack-Smith 1962, Kenny & Haysom 1962, Lowry *et al.* 1978). Of 84 fish collected in recent years by ANARE expeditioners, by angling or fish traps in the kelp zone or from beach strandings, 76 (90.5%) were *P. magellanica*. Most specimens known from Macquarie Island display the usual colouration of this species described by DeWitt (1970), being drab brown/olive above, with shades of yellow or red on the belly or throat region. Photographs of one fish 275 mm long, stranded in a rock pool (the specimen was not preserved), show it to have bright "electric" blue upper parts and bright silvery underparts, unmarked except for the characteristic yellow-coloured branchiostegal membranes. Another specimen about 365 mm long, found stranded on a beach, indicated a similar colouration, but was too long dead for certainty. Both these specimens were far too large to be still in the known pelagic juvenile phase of this species, and this colour pattern in the adult seems characteristic of those adults that revert to a pelagic habit. This habit is well documented, large specimens having been taken in pelagic nets in the Ross Sea (DeWitt 1970), in the vicinity of South Georgia and the South Orkney Islands (Permitin 1969), and in the South Pacific Ocean (Hureau 1985b), but, unfortunately, none of these authors adequately described the colour of the specimens.

Small *P. magellanica* (mean weight 26.5 g) are the major constituent of the diet of the king shag *Phalacrocorax albiventer purpurascens*, accounting for at least 47.3% by weight, and probably considerably more, as 44.4% by weight of the stomach contents were only identifiable as

"*Notothenia* spp." (Brothers 1985). It is a major constituent of the diet of gentoo penguins (Hindell, in press, b) and a minor constituent in rockhopper penguins *Eudyptes chrysocome* (Hindell, in press, c) and royal penguins *Eudyptes schlegeli* (Hindell, in press, d).

This species is the most widespread and common of the subantarctic nototheniids, known from Patagonia, the Falkland Islands and the Scotia Sea, through all the subantarctic islands to southern New Zealand (Hureau 1985b).

***Paranotothenia microlepidota* (Hutton)**

One example of this species has been recorded by Waite (1916) as *Notothenia colbecki*, caught in the kelp zone by angling. This fish is characteristic of the New Zealand region, being found around the South Island and all the small islands to the south (DeWitt 1970), and at the Auckland and Campbell Islands and the Snares (Graham 1953).

Family Harpagiferidae

***Harpagifer georgianus georgianus* Nybelin**

This species was reported as common in the intertidal and subtidal zones by Waite (1916), Norman (1937) and Slack-Smith (1962). Lowry *et al.* (1978) reported small specimens (up to 90 mm SL) common under boulders and stones in water up to 20 m deep. The trawling survey extended its offshore range to 100 m depth. Twenty-four specimens (2.2% of total catch) were caught in hauls 4, 5 and 9 off the east and north coasts, in depths between 57 and 100 m. The species constituted 8.3% by weight of the stomach contents of the king shag, studied by Brothers (1985), and is a minor component in the diets of gentoo and rockhopper penguins (Hindell, in press, b, c), and royal penguins (Horne 1985).

All the above-quoted authors refer to this species as *H. bispinis*, a name which originally covered specimens of this circum-subantarctic genus from all localities. A revision of the genus by Hureau *et al.* (1979), however, tentatively identified a single specimen from Macquarie Island as *H. georgianus georgianus*, which also occurred near South Georgia and Marion Islands. *Harpagifer* at other intermediate localities were assigned to *H. georgianus palliolatus* (Falkland Islands), *H. bispinis (Patagonia), H. antarcticus* (Antarctic Peninsula), *H. spinosus* (Iles Crozet) and (*H. kerguelensis* (Iles Kerguelen). Examination of 18 specimens collected by Lowry and housed in the Australian Museum, and 24 collected by the trawling survey, confirms this identification. The major diagnostic character, the head length as a percentage of the SL, has a mean of 37.38% ± 2.585 SD, which agrees well with the >35% for *H. georgianus* (Hureau *et al.* 1979), and most of the morphological and meristic characters fall within the ranges specified. The form of the supra-orbital processes and of the pores of the cephalic canal system are also consistent with *H. g. georgianus*.

ANNOTATED CHECKLIST OF FISHES — PELAGIC SPECIES

The following pelagic species are now known from Macquarie Island.

Family Bathylagidae

***Bathylagus* sp.**

Two specimens were caught in RMT haul 3, at 250–500 m depth off the east coast.

Family Gonostomatidae

***Cyclothone* sp.**

Five specimens were caught in RMT hauls 1 and 5, between 100 and 500 m depth off the east coast.

***Maurolicus mulleri* (Gmelin)**

One specimen was stranded on an east coast beach in July 1980.

Family Stomiatidae

***Stomias gracilis* Garman**

One specimen was caught in RMT haul 3, in 250–500 m depth off the north coast.

Family Myctophidae

***Krefftichthys anderssoni* (Lonnberg)**

Two adults (with caudal light organs) were caught in RMT hauls 3 and 5, at 250–500 m depth off the east and north coasts. A total of 35 larvae were caught in hauls 1, 2, 4 and 5, from a depth range of 50–500 m. Sixteen specimens caught in a plankton net in Buckles Bay, identified as *Myctophum* sp. juveniles by Slack-Smith (1962), are, in fact, *K. anderssoni*. Whitley (1941) reported two specimens of this species (as *Myctophum anderssoni*) obtained by AAE. The characters he describes are consistent with the definition of *K. anderssoni* by Hulley (1981); the latter is also a major constituent of the diet of all four penguin species studied by Hindell (in press) (table 2).

TABLE 2

Presence of Fish in Penguin Diets*

Species	Frequency of occurrence	% by number	% by weight
KING PENGUIN			
Krefftichthys anderssoni	68	48.1	37.8
Protomyctophum spp.	22	1.0	0.9
Electrona carlsbergi	71	48.5	53.2
Gymnoscopelus spp.	3	0.3	0.3
Magnisudis prionosa	29	0.3	4.5
GENTOO PENGUIN			
Krefftichthys anderssoni	59	35.0	15.1
Protomyctophum spp.	9	1.7	0.8
Electrona carlsbergi	48	48.8	27.5
Gymnoscopelus spp.	39	6.3	15.7
Magnisudis prionosa	3	+	0.4
Notothenia rossii	6	0.2	2.0
Paranotothenia magellanica	28	2.3	18.4
Harpagifer georgianus	13	0.7	0.5
Zanclorhynchus spinifer	6	0.1	0.9
ROCKHOPPER PENGUIN			
Krefftichthys anderssoni	23	0.4	16.0
Protomyctophum spp.	4	+	0.3
Electrona carlsbergi	5	0.1	2.2
Gymnoscopelus spp.	5	+	4.6
Paranotothenia magellanica	21	0.3	1.8
Harpagifer georgianus	10	0.3	0.4
Zanclorhynchus spinifer	4	+	3.0
ROYAL PENGUIN			
Krefftichthys anderssoni	48	1.3	23.7
Protomyctophum spp.	14	0.1	3.8
Electrona carlsbergi	30	0.8	9.6
Gymnoscopelus spp.	6	+	4.0
Magnisudis prionosa	10	+	3.6
Paranotothenia magellanica	4	+	+

* Data from Hindell (in press, a,b,c,d). + = less than 0.1%

***Protomyctophum (Protomyctophum) bolini* (Fraser-Brunner)**

A total of 24 specimens (5 adults with caudal light organs and 19 juveniles) were caught in RMT hauls 3 and 5, at 250–500 m depth off the east and north coasts.

***Protomyctophum (Hierops) parallelum* (Lonnberg)**

One adult male and 14 juveniles were caught in RMT haul 5, at 250–500 m depth off the north coast.

***Electrona antarctica* (Gunther)**

One juvenile specimen was caught in RMT 5, at 250–500 m depth off the north coast.

***Electrona carlsbergi* (Taning)**

Three adult female specimens were caught in RMT 3, at 250–500 m depth off the east coast. One specimen has been found stranded on an east coast beach. This species forms a major part of the diet of gentoo and king penguins (Hindell, in press, a, b; G. Robertson, pers. comm.), and a minor constituent in rockhopper and royal penguins (table 2).

***Electrona subaspera* (Gunther)**

One adult female was caught in RMT haul 3, at 250–500 m depth, and one juvenile in haul 4, at 50 m depth, both off the east coast. Waite (1916) described two specimens found stranded on the beach as *Myctophum antarcticum*, but his description and illustration fit the diagnosis of *E. subaspera* given by Andriashev (1962) very well; the photophore patterns, particularly the PVO and PLO forming an equilateral triangle, the absence of an So and the position of the VLO, point to this species.

Other evidence indicates that this is one of the commonest pelagic species in the vicinity of the island. It is the major constituent of the summer diet of gentoo penguins, both by frequency of occurrence and by weight (D. Robertson, pers. comm.), and is the most commonly stranded pelagic fish, including a mass mortality observed by Merilees (1984), where about 90% of the thousands of fish stranded were *E. subaspera*.

***Gymnoscopelus (Gymnoscopelus) bolini* Andriashev**

Two specimens were caught in RMT haul 2, at 50 m depth off the east coast.

***Gymnoscopelus (G.) braueri* (Lonnberg)**

Three specimens were caught in RMT haul 3, at 250–500 m depth off the east coast.

***Gymnoscopelus (G.) nicholsi* (Gilbert)**

One specimen was caught in RMT haul 2, at 50 m depth off the east coast.

***Gymnoscopelus (Nasolychnus) hintonoides* Hulley**

Five specimens were caught in RMT hauls 3 and 5, at 250–500 m depth off the east coast.

***Gymnoscopelus (N.) microlampas* Hulley**

One specimen was caught in RMT haul 5, at 250–500 m off the east coast.

***Gymnoscopelus (N.) piabilis* (Whitley)**

Two specimens were caught in RMT haul 2, at 50 m depth off the east coast. Macquarie Island is the type locality of this species, described by Whitley (1931) from three beach-stranded specimens originally recorded by Waite (1916) as *Lampanyctus braueri*. Three specimens found on Macquarie Island beaches, and now in the CSIRO collection (CA3120, A3575, A3576), also belong to this species. Merilees (1984) reported that about 6% of the mass fish mortality he described comprised *Gymnoscopelus braueri*. Although no specimens were available for study, photographs showed, by the presence of antorbital luminous tissue extending below the upper half of the orbit, the relative positions of VO_5, SAO_1 and SAO_2 and the very dusky pelvic fins, that the species concerned was in fact *G. piabilis*.

A *Gymnoscopelus* species is a significant component of the summer diet of gentoo penguins (D. Robertson, pers. comm.), and where the stomach contents contained relatively intact fish, these had the antorbital luminous tissue characteristic of the subgenus *Nasolychnus*. On the evidence of the mass mortality and other beach strandings, and the fact that *G. piabilis* was the only Nasolychnus species caught in the 50 m RMT haul and thus within the diving range of the penguins, it is probable that most of the *Gymnoscopelus* sp. in the penguin diet were in fact *G. piabilis*.

Family Scopelosauridae

***Scopelosaurus hamiltoni* (Waite)**

One specimen 505 mm long was found stranded on a beach by AAE and reported by Waite (1916) as a new species *Notosudis hamiltoni*. It was placed in the family Scopelosauridae as *Scopelosaurus hamiltoni* by Marshall (1966).

Family Paralepididae

***Magnisudis prionosa* (Rofen)**

One specimen (head only), estimated standard length 270 mm, was recovered from a king penguin (Hindell, in press, a).

Family Alepisauridae

***Alepisaurus brevirostris* Gibbs**

One specimen, 606 mm SL, was found stranded on the beach in June 1983. The shortness of the head (13.9% of SL) and forward origin of the dorsal fin (over the operculum) enable specific identification from Gibbs & Wilmovsky (1966). The two species of *Alepisaurus* are widely distributed in temperate and tropical waters (Parin 1970), but several adult specimens of *A. brevirostris* have been found in subantarctic localities such as the Crozet Islands (Hureau 1968, Shcherbachev & Meysner 1973) and Iles Kerguelen (Duhamel & Hureau 1982). Its occurrence at Macquarie Island is the most southerly record of this species.

TABLE 3

Presence of Species Found at Macquarie Island at Other Southern Localities

Species	Zones* in which fish occur				
	N.Z.	Aust.	Kerguelen	Antarctica	Scotia
Somniosus microcephalus	(+)	R	(+)		
Muraenolepis marmoratus			+		
Centriscops cf. humerosus	(+)	(+)			
Zanclorhynchus spinifer			+		
"Neophrynichthys" magnicirrus	R	(R)			
Ebinania macquariensis	R	R			
Dissostichus eleginoides			+	R	+
Notothenia rossii rossii			+		+
Notothenia squamifrons			+		+
Paranotothenia magellanica	+		+	+	+
Paranotothenia microlepidota	+				
Harpagifer georgianus georgianus			R		+

* Zones are defined as follows:
Kerguelen = Kerguelen, Heard, Bouvet, Crozet, Marion & Prince Edward Islands, Ob' and Lena banks;
N.Z. = New Zealand (South Island), Chatham, Campbell, Auckland, Bounty and Antipodes Islands;
Aust. = southern coast of Australia, including Tasmania;
Antarctica = Balleny Islands and Antarctic continent excluding Antarctic Peninsula;
Scotia = southern tip of South America, South Georgia, South Sandwich, South Orkney, South Shetland Islands and Antarctic Peninsula.

(+) = species present as indicated if Macquarie specimens are correctly identified.
R = a closely related species (at least in the same genus) is present.

Family Bramidae

***Brama* sp.**

One specimen (head only) was obtained from a gentoo penguin by G. Robertson, but was not sufficiently complete to allow specific identification. *Brama brama* is known from the North Atlantic and throughout the Southern Hemisphere, and is locally abundant in New Zealand (Paulin 1981), but usually keeps to waters not below 13°C and never goes beyond the 10°C isotherm (Parin 1970). Several specimens are known from southern Australia which may be of an undescribed species (P.R. Last, pers. comm.). The Macquarie Island specimen most probably has affinities with an Australasian species, no matter what its real identity, and certainly represents a large extension of the range of this genus.

Family Gempylidae

***Paradiplospinus gracilis* (Brauer)**

Five larvae 10–26 mm SL were caught in RMT haul 2, in 50 m depth off the east coast.

DISCUSSION

The zoogeographical relationships of the Macquarie Island fish fauna are best demonstrated by the benthic species. The augmented species list presented here indicates that the strongest affinity still lies with the Indian Ocean subantarctic islands to the west, as first proposed by Regan (1916) and followed by Norman (1938), Nybelin (1947), Andriashev (1965) and DeWitt (1971), on the basis of only six species known from Macquarie Island by those authors. Table 3 shows that, of the 12 species recorded from Macquarie Island, eight are shared with the Kerguelen Zone (here defined as including all subantarctic islands in the Indian Ocean sector), including the most abundant species (*Notothenia squamifrons*, *Paranotothenia magellanica*, *Harpagifer georgianus georgianus* and *Zanclorhynchus spinifer*). Six of the Macquarie Island species, including three of the four most common species, belong to the Notothenioidei which are typically associated with antarctic and subantarctic waters, as is the genus *Muraenolepis*. Five of the Notothenioidei are also shared with the

TABLE 4

Presence of nototheniids and channichthyids at Locations in the Indian sector of the Southern Ocean

	Marion Prince Edward	Crozet	Kerg-uelen	Heard	Ob' and Lena	Bouvet	Mac-quarie
Nototheniidae							
Dissostichus eleginoides	+	+	+	+	+	+	+
Notothenia rossii rossii	+	+	+	+	+		+
N. coriiceps coriiceps	+	+	+	+		*	
N. squamifrons	+	+	+	+	+	+	+
N. cyanobrancha			+	+			
N. acuta	+	+	+	+			
N. marionensis	+						
Paranotothenia magellanica	+	+	+	+			+
Nototheniops mizops			+	+			
N. tchizh	+	+			+		
Channichthyidae							
Champsocephalus gunnari			+	+		+	
Channichthys rhinoceratus			+	+			

* = *Notothenia coriiceps neglecta*

islands of the Scotia Arc and Antarctic Peninsula. All these similarities point unequivocally to an antarctic affinity, specifically to the Kerguelen Zone.

Despite this, there are some significant differences which set the fish fauna of Macquarie Island apart from the other islands in the Kerguelen Zone.

Firstly, table 4 shows that, just as DeWitt (1971) observed a diminution in the number and variety of species in the Kerguelen–Macquarie region compared with the more westerly Scotia Ridge, so the eastern outlier, Macquarie Island, lacks elements of the fauna widespread throughout the rest of the Kerguelen Zone. Members of the family Channichthyidae, which are characteristic of cold waters near to or south of the Antarctic Convergence (Duhamel *et al.* 1983), have not yet been found at Macquarie Island despite its proximity to the Convergence and a similar water temperature regime to the Kerguelen Zone, where they are abundant. Also, of the ten Nototheniidae species known from the Kerguelen Zone, only four are found at Macquarie Island (table 4), whereas the other islands have seven or eight species, some of which are endemic (*Notothenia marionensis* at Marion and Prince Edward Islands, *N. cyanobrancha* and *Nototheniops mizops* at Kerguelen and Heard Islands). All the nototheniid species found at Macquarie Island are known to spend at least the first year of their life in a pelagic juvenile stage before settling, in most cases, to a more benthic habit; it is not surprising that, under the influence of the West Wind Drift, they have reached Macquarie Island and come to dominate its fauna. More surprisingly, other nototheniids, which are generally common, widespread and also have pelagic juvenile stages, have not colonised the Macquarie Island region as successfully as *N. squamifrons* and *Paranotothenia magellanica*.

Secondly, Macquarie Island shows a stronger influence of species associated with temperate areas to the north than do the islands of the Kerguelen Zone, despite their similar positions relative to the Antarctic Convergence. From its complement of 12 benthic species, five belong to groups typical of the Australia/New Zealand temperate region (table 3). There is a much larger shelf area around Iles Kerguelen and, by virtue of the large commercial fishery there since 1969, the sampling effort has been much greater. Nevertheless, from the 35 benthic species known from depths less than 1000 m, only three species of shark (*Somniosus microcephalus*, *Lamna nasus* and *Etmopterus lucifer*) can be considered atypical of the Antarctic Zone (Hureau 1979, Duhamel & Hureau 1982). It should be remembered, though, that all the "temperate" species occur rarely at Macquarie Island or are known only from single specimens.

Among the pelagic species, there is an overwhelming dominance of myctophids. Seventy of the 83 fish caught in the RMT hauls (84%) were myctophids, and table 2 shows that their percentage by weight in the diets of the four common penguins on the island ranged from 23% in the rockhopper penguin to 92% in the king penguin, indicating the availability of large numbers of these fish close to the island. The myctophid species list reflects the position of the island just north of the Antarctic Convergence. Most of the species encountered live and spawn between the Antarctic and Subtropical Convergences and fall into the subantarctic distribution pattern of Hulley (1981). *Krefftichthys anderssoni*, *Protomyctophum (Protomyctophum) bolini*, *Electrona carlsbergi* and *Gymnoscopelus (G.) braueri*, however, also range south of the Antarctic Convergence, while *E. antarctica* is only found south of it, except for some juveniles (as encountered at Macquarie Island) which occur to the north. Thus, of the 16 myctophid species reported to occur near the Antarctic Convergence by Hulley (1981), 12 have been found at Macquarie Island. All appear to be circum-antarctic within their latitudinal ranges.

Among the other pelagic fish, two species demonstrate antarctic affinities. *Magnisudis prionosa* is found in the southern Atlantic and Pacific Oceans, and sometimes south of the Antarctic Convergence, near South Georgia and the Antarctic Continent (Post 1985). Adults of *Paradiplospinus gracilis* are usually found south of the Antarctic Convergence, where they feed on krill (Mikhaylin 1976), but they spawn north of the Convergence and larvae have so far been found as far north as 34°40'S, off Chile, near the Antarctic Peninsula, and off Argentina (Parin & Bekker 1972). It was originally thought that the juveniles lived at much deeper levels than the adults (Bussing 1965), but Nishikawa (1984) caught juveniles in 20–50 m depth off South Africa, and their presence in 50 m depth at Macquarie Island confirms their epipelagic habit as juveniles.

The remaining two species, Brama sp. and Alepisaurus brevirostris, as described above, demonstrate a link with temperate waters to the north.

SUMMARY

As a result of recent sampling activity and searches of previous collections and records, the number of fish species known from the nearshore waters of Macquarie Island has been increased from 8 benthic and 4 pelagic to 12 benthic and 21 pelagic species. Although Macquarie Island lies just north of the Antarctic Convergence, this list demonstrates that the fish fauna has largely antarctic affinities.

Among the 12 benthic species, six belong to the antarctic suborder Notothenioidei, only a few representatives of which are found north of the Antarctic Convergence. Five of these (*Dissostichus eleginoides*, *Notothenia squamifrons*, *N. rossii*, *Paranotothenia magellanica* and *Harpagifer georgianus*), together with *Muraenolepsis marmoratus* and the congiopodid *Zanclorhynchus spinifer*, demonstrate close affinity with the fish fauna of other subantarctic islands, such as Iles Kerguelen. The final nototheniid, *Paranotothenia microlepidota*, is also found around islands to the south of New Zealand. Of the remainder, three (*Neophrynichthys magnicirrus*, *Ebinania macquariensis* and *Centriscops humerosus*) are members of families typically found in cool Indo-Pacific waters; the last, *Somniosus microcephalus*, is well known around Iles Kerguelen.

Twelve of the pelagic species belong to the family Myctophidae, all well known from the zone between the Antarctic and Subtropical Convergences. The remaining nine are members of families which have southern cool temperate distributions (Gonostomatidae, Alepisauridae, Paralepididae, Scopelosauridae, Bathylagidae, Stomiatidae, Gempylidae and Bramidae), and seem to be at the southern extremities of their ranges.

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REFERENCES

ANDRIASHEV, A.P., 1962: Bathypelagic fishes of the Antarctic 1. Family Myctophidae. *Biol. Rep. Sov. Antarct. Exped.*, 1: 216–300.

ANDRIASHEV, A.P., 1965: A general review of the Antarctic fish fauna. *In* Van Oye, P., Van Mieghem J. & Schell J. (Eds): *BIOGEOGRAPHY AND ECOLOGY IN ANTARCTICA*. Junk, The Hague: 491–550.

BROTHERS, N.P., 1985: Breeding biology, diet and morphometrics of the king shag, *Phalacrocorax albiventer purpurascens* at Macquarie Island. *Aust. Wildl. Res.*, 12: 81–94.

BUSSING, W.A., 1965: Studies of the midwater fishes of the Peru-Chile Trench. *Antarct. Res. Ser.*, 5: 185–227.

CULLEN, D.J., 1970: Macquarie Island. Provisional bathymetry. *N.Z. Oceanogr. Inst. Chart*, Island Ser., 1:200,000.

DeWITT, H.H., 1970: A revision of the fishes of the genus *Notothenia* from the New Zealand region, including Macquarie Island. Proc. *Calif. Acad. Sci.*, 38: 299–340.

DeWITT, H.H., 1971: Coastal and deep water benthic fishes of the Antarctic. *Antarct. Map Folio Ser.* no.15. American Geographical Society, New York.

DUHAMEL, G., 1982: Biology and population dynamics of *Notothenia rossii rossii* from the Kerguelen Islands (Indian sector of Southern Ocean). *Polar Biol.*, 1: 141–151.

DUHAMEL, G. & HUREAU, J.-C., 1982: Donnees complementaires sur l'ichtyofaune des iles australes francaises. *Cybium*, 6: 65–80.

DUHAMEL, G., HUREAU, J.-C. & OZOUF-COSTAZ, C., 1983: Ecological survey of the notothenioid fishes in the Southern Ocean from Bouvet to Kerguelen Islands. *Proc. Nat. Inst. Polar Res. Tokyo Special Issue*, 27: 176–182.

DUHAMEL, G. & OZOUF-COSTAZ, C., 1985: Age, growth and reproductive biology of *Notothenia squamifrons* Gunther, 1880 from the Indian sector of the Southern Ocean. *Polar Biol.*, 4: 143–153.

GIBBS, R.H. & WILIMOVSKY, N.J., 1966: Family Alepisauridae. *In* Olsen, Y.H. & Atz, J.W. (Eds): *FISHES OF THE WESTERN NORTH ATLANTIC. Mem. Sears Found. Mar. Res.*, 1(5): 482–497.

GRAHAM, D.H., 1953: A TREASURY OF NEW ZEALAND FISHES. Reed, Wellington.

HINDELL, M.A., in press, a: The diet of the King Penguin, *Aptenodytes patagonicus*, at Macquarie Island. *Emu.*

HINDELL, M.A., in press, b: The diet of Gentoo Penguins, *Pygoscelis papua*, at Macquarie Island: winter and early breeding season. *Emu.*

HINDELL, M.A., in press, c: The diet of the Rockhopper Penguin, *Eudyptes chrysocome*, at Macquarie Island. *Emu.*

HINDELL, M.A., in press, d.: The diet of the Royal Penguin, *Eudyptes schlegeli*, at Macquarie Island. *Emu.*

HORNE, R.S.C., 1985: Diet of royal and rockhopper penguins at Macquarie Island. *Emu*, 85: 150–156.

HULLEY, P.A., 1981: Results of the research cruises of FRV "Walther Herwig" to South America. LVIII. Family Myctophidae (Osteichthyes, Myctophiformes). *Arch. FischWiss.*, 31: 1–300.

HUREAU, J.-C., 1968: Presence d'un *Alepisaurus* aux Iles Crozet poisson jamais signale dans l'hemisphere sud. *Bull. Mus. Hist. Nat.*, 39(5): 833–837.

HUREAU, J.-C., 1979: La faune ichthyologique du secteur indien de l'Ocean Antarctique et estimation du stock de poissons autour des iles Kerguelen. *Mem. Mus. natn. Hist. Nat.*, Ser. C, 43: 235–247.

HUREAU, J.-C., 1985a: Congiopodidae. In Fischer, W. & Hureau, J.-C. (Eds): *FAO SPECIES IDENTIFICATION SHEETS FOR FISHERY PURPOSES. SOUTHERN OCEAN.* FAO, Rome: 278–279.

HUREAU, J.-C., 1985b: Nototheniidae. In Fischer, W. & Hureau, J.-C. (Eds): *FAO SPECIES IDENTIFICATION SHEETS FOR FISHERY PURPOSES. SOUTHERN OCEAN.* FAO, Rome: 323–385.

HUREAU, J.-C., LOUIS, J., TOMO, A. & OZOUF, C., 1979: Application de l'analyse canonique discriminante a la revision du genre *Harpagifer* (Teleosteens, Nototheniiformes). *Vie Milieu*, 28–29: 287–306.

KENNY, R. & HAYSOM, N., 1962: Ecology of rocky shore organisms at Macquarie Island. *Pacif. Sci.*, 16: 245–263.

LOWRY, J.K., HORNING, D.S., POORE, G.C.B. & RICKER, R.W., 1978: *THE AUSTRALIAN MUSEUM MACQUARIE ISLAND EXPEDITION, SUMMER 1977–1978.* Australian Museum Trust, Sydney.

MARSHALL, N.B., 1966: Family Scopelosauridae. *In* Olsen, Y.H. & Atz, J.W. (Eds): *FISHES OF THE WESTERN NORTH ATLANTIC. Mem. Sears Found. Mar. Res.*, 1(5): 194–204.

MAY, J.L. & MAXWELL, J.G.H., 1986: *FIELD GUIDE TO TRAWL FISH FROM TEMPERATE WATERS OF AUSTRALIA.* CSIRO, Hobart.

MERILEES, W., 1984: On a mass mortality of lantern fish at Macquarie Island. *Tasm. Nat.*, 78: 32.

MIKHAYLIN, S.V., 1976: Characteristics of the distribution of some members of the Families Gempylidae and Trichiuridae in the waters of Southwest Africa. *J. Ichthyol.*, 16: 319–323.

MOHR, E., 1937: Revision der Centriscidae (Acanthopterygii Centrisciformes). *Dana Rep.*, 13: 1–70.

NELSON, J.S., 1977: Fishes of the southern hemisphere Genus *Neophrynichthys* (Scorpaeniformes: Cottoidei), with descriptions of two new species from New Zealand and Macquarie Island. *J. R. Soc. N.Z.*, 7(4): 485–511.

NELSON, J.S., 1982: Two new south pacific fishes of the Genus *Ebinania* and contributions to the systematics of Psychrolutidae (Scorpaeniformes). *Can. J. Zool.*, 60: 1470–1504.

NISHIKAWA, Y., 1984: Postlarval development of the gempylid fish *Paradiplospinus gracilis* (Brauer). *Bull. Far Seas Fish. Res. Lab.*, 21: 1–7.

NORMAN, J.R., 1937: Fishes. *BANZARE Rep.*, Ser. B(1),2: 49–88.

NORMAN, J.R., 1938: Coast fishes, Part III. The Antarctic zone. "*Discovery*" *Rep.*, 18: 1–104.

NYBELIN, O., 1947: Antarctic fishes. *Sci. Res. Norw. Antarct. Exped. 1927–1928*, 2(26): 1–76.

PARIN, N.V., 1970: *ICHTHYOFAUNA OF THE EPIPELAGIC ZONE.* Israel Program for Scientific Translations, Jerusalem.

PARIN, N.V. & BEKKER, V.E., 1972: Materials on taxonomy and distribution of some trichiuroid fishes (Pisces:Trichiuroidae, Scombrolabracidae, Gempylidae and Trichiuridae). *Trudy Inst. Okeanol.*, 93: 110–204.

PAULIN, C.D., 1981: Fishes of the Family Bramidae recorded from New Zealand. *N.Z. J. Zool.*, 8: 25–31.

PERMITIN, Y.Y., 1969: New data on species composition and distribution of fishes in the Scotia sea, Antarctica (Second communication). *J. Ichthyol.*, 9: 221–239.

POST, A., 1985: Paralepididae. *In* Fischer, W. & Hureau, J.-C. (Eds): *FAO SPECIES IDENTIFICATION SHEETS FOR FISHERY PURPOSES. SOUTHERN OCEAN.* FAO, Rome: 386–395.

REGAN, C.T., 1916: Bibliographical notice: Antarctic and subantarctic fishes. *Ann. Mag. Nat. Hist., Lond.*, Ser. 8(18): 377–379.

SHCHERBACHEV, Y.N. & MEYSNER, E.E., 1973: Discovery of the shortnose lancetfish [*Alepisaurus brevirostris* (Gibbs)] in subantarctic waters of the Indian Ocean. J. *Ichthyol.*, 13: 778–780.

SIMPSON, R.D., 1976: The shore environment of Macquarie Island. *ANARE Sci. Rep.*, Ser. B(1), Zoology. Antarctic Division, Melbourne.

SLACK-SMITH, R.J., 1962: A small collection of fish from Macquarie Island. *Mem. Nat. Mus. Melb.*, 25: 13–16.

SUMMERHAYES, C.P., 1967: Macquarie Bathymetry. *N.Z. Oceanogr. Inst. Chart.* Oceanic Series, 1:1,000,000.

TOMO, A. & HUREAU, J.-C., 1985: Muraenolepididae. *In* Fischer, W. & Hureau, J.-C. (Eds): *FAO SPECIES IDENTIFICATION SHEETS FOR FISHERY PURPOSES. SOUTHERN OCEAN.* FAO, Rome: 306–315.

WAITE, E.R., 1916: Fishes. *AAE Sci. Rep.*, Ser. C(3), 1: 1–92.

WHITLEY, G.P., 1931: Studies in ichthyology no.4. *Rec. Aust. Mus.*, 18(3): 96–133.

WHITLEY, G.P., 1939: Taxonomic notes on sharks and rays. *Aust. Zool.*, 9: 227–262.

WHITLEY, G.P., 1941: A lantern fish from Macquarie Island. *Aust. Zool.*, 10(1): 124.

WILLIAMS, R., 1983: Australia's sub-Antarctic outposts — anything for fishermen? *Aust. Fish. Newsl.*, 42(7): 12–14.

WILLIAMS, R., 1984: Inshore fishes of Macquarie Island. *Tasm. Nat.*, 78: 30–31.

(accepted 25 September 1987)

INTERRELATIONSHIPS BETWEEN WIND EXPOSURE, VEGETATION DISTRIBUTION AND POLLEN FALLOUT BETWEEN BAUER BAY AND SANDY BAY, MACQUARIE ISLAND

by J.A. Peterson and J.J. Scott

(with one table and six text-figures)

PETERSON, J.A. & SCOTT, J.J., 1988 (viii): Interrelationships between wind exposure, vegetation distribution and pollen fallout between Bauer Bay and Sandy Bay, Macquarie Island. *Pap. Proc. R. Soc. Tasm.* 122(1): 247–253. Paper presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Geography, Monash University, Clayton, Victoria, Australia 3168.

Analyses of data collected during the summer of 1979–80 from pollen traps and a flag tatter experiment along a transect across Macquarie Island, between Bauer Bay and Sandy Bay, suggest that the most sheltered locations are in the lee of prominent ridges, especially below the eastern coastal cliff tops, but also, paradoxically, on the lower slopes of the windward (west) coast. The presence of feldmark community pollen grains from "down wind" and higher altitudes in the west coast pollen traps indicates that, during the period here documented, the island formed a topographic barrier such that when there were winds from westerly quarters of sufficient velocity, not only would the predictable lee side rotor circulations have been produced, but also a trapped windward (west coast) rotor that, at low altitudes, would have run counter to the prevailing winds. Flag tatter data from the most exposed sites indicate local wind climates of greater severity than any measured in the same way at comparable maritime latitudes across similar topographic barriers elsewhere. It can be inferred that windward rotors are not uncommon on Macquarie Island.

The effectiveness of Macquarie Island as a barrier to local ocean and atmospheric circulation is a function of balances between tectonic and denudational (including marine) processes and glacial eustasy, and would have varied over time. This, and the resulting effect of local wind circulation on fallout patterns, need to be considered when interpreting pollen diagrams.

Key Words: Macquarie Island, rotor circulation, pollen fallout, vegetation patterns, wind exposure.

INTRODUCTION

The general distribution of natural vegetation communities on Macquarie Island has been explained largely in terms of variation in altitude, soil moisture, and exposure to wind. The major vegetation communities (after Seppelt & Hughes, in press) are fellfield (feldmark), herbfield, maritime (tall tussock) grassland, and short tussock grassland/meadow or meadow grassland. Wet mires, swamps, and fern brake communities have a more localised occurrence. Feldmark occurs above about 200 m in exposed locations; the herbfield in somewhat wetter locations, some of which are as high as 370 m and sheltered from the strongest wind velocities; maritime (tall tussock) grassland occurs on coastal terraces, steep coastal slopes and occasional upland flats where there is protection from the strongest winds (see Taylor 1955). In these terms, vegetation maps of the island (e.g. Taylor 1955) present something of a paradox, in that the tall tussock grassland is found both on the exposed windward face of the island and on the lee slopes. Continuous weather records are almost wholly confined to the meteorological station (approx. 6 m a.s.l.), which is sheltered by North Head and the bluffs at the north end of the plateau (fig. 1; see also De Lisle 1965). Station data will need to be supplemented with measurements and analyses from other sites before the range of local wind climates can be documented. Such a task is relevant not only to climatic studies but to other enquiries, including any which aim to optimise the placement of pollen traps for studying the nature of fallout (e.g. exotic pollen, Salas 1983) or the calibration of (Quaternary) pollen diagrams.

Variety in local wind climates has already been recognised on Macquarie Island. Jenkin (1972) reported from data, taken over 90 days during the periods August–October 1965 and February 1966, that wind run on the plateau at 200 m was, on average, 32% greater than that measured at the meteorological station. This is supported by data collected during the summer of 1980–81 (fig. 2). Hnatiuk (1975) monitored five sites at the north end of the island for 62 days in

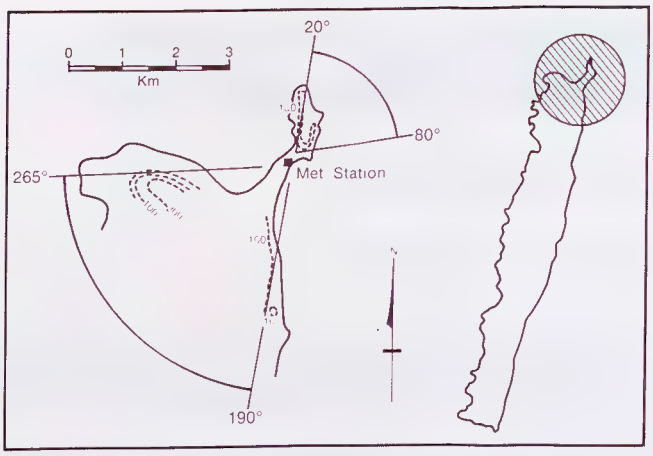

FIG. 1 — Diagram indicating topographic mitigation of exposure to wind at Macquarie Island Meteorological Station.

1970, using the flag tatter technique of Lines & Howell (1963), and concluded, from a brief analysis that wind exposure was not directly related to altitude, and that the range of local wind climates evident was controlled by aspect and the distribution of natural wind breaks such as hill crests. These are generally marked by abrupt changes in vegetation associations (e.g. Copson 1984).

In an attempt to elucidate the environmental gradient between windward and leeward slopes of the island, the flag tatter method was used to monitor windiness during the summer of 1979–80. Eight stations were set up along a transect established by the Tasmanian National Parks and Wildlife Service in 1977 to encompass the major vegetation communities, as part of a programme to monitor rabbit grazing (see fig. 3). Oldfield pollen traps were placed near each flag station and changed at the end of the season, and surface samples were collected from natural pollen traps such as moss polsters, as part of a study of the modern pollen rain.

METHODS

Madapollam cotton flags (0.2 m x 0.25 m) were prepared for gluing to a free-turning spindle revolving on an axis attached to a star picket so that the flag stood 1.6 m high. Before deployment, the flags were tested for structural integrity by exposure to 30 knot winds for ten minutes, so that any flags predisposed to rip or tear could be eliminated. A control flag was established next to the meteorological station wind-run anemometer (at 3 m above ground level).

Previous workers (e.g. Rutter 1968) have debated the merits of taking measurements of the flag area in the field (e.g. by pricking the outline of the flag on graph paper) and re-using it after trimming the protective fringe that inevitably develops if any significant tatter has occurred. The trimming allows weight and area loss rates to be parallel so that there is the option to present results in terms of weight and area loss. However, this tends to exaggerate losses from flags in sheltered sites (Rutter 1968). On the other hand, the untrimmed flags tend to rip, so that, although by that stage weight loss has caught up with area loss, the rate of area loss is not constant. It was decided to measure cumulative area loss week by week with untrimmed flags and to re-use the less tattered flags by recording successive areas by pricking around

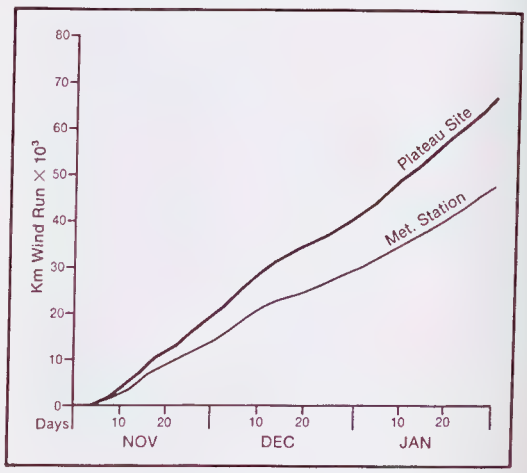

FIG. 2 — Comparison of concurrent wind run at the meteorological station and on Perseverance Bluff during the summer of 1980–81.

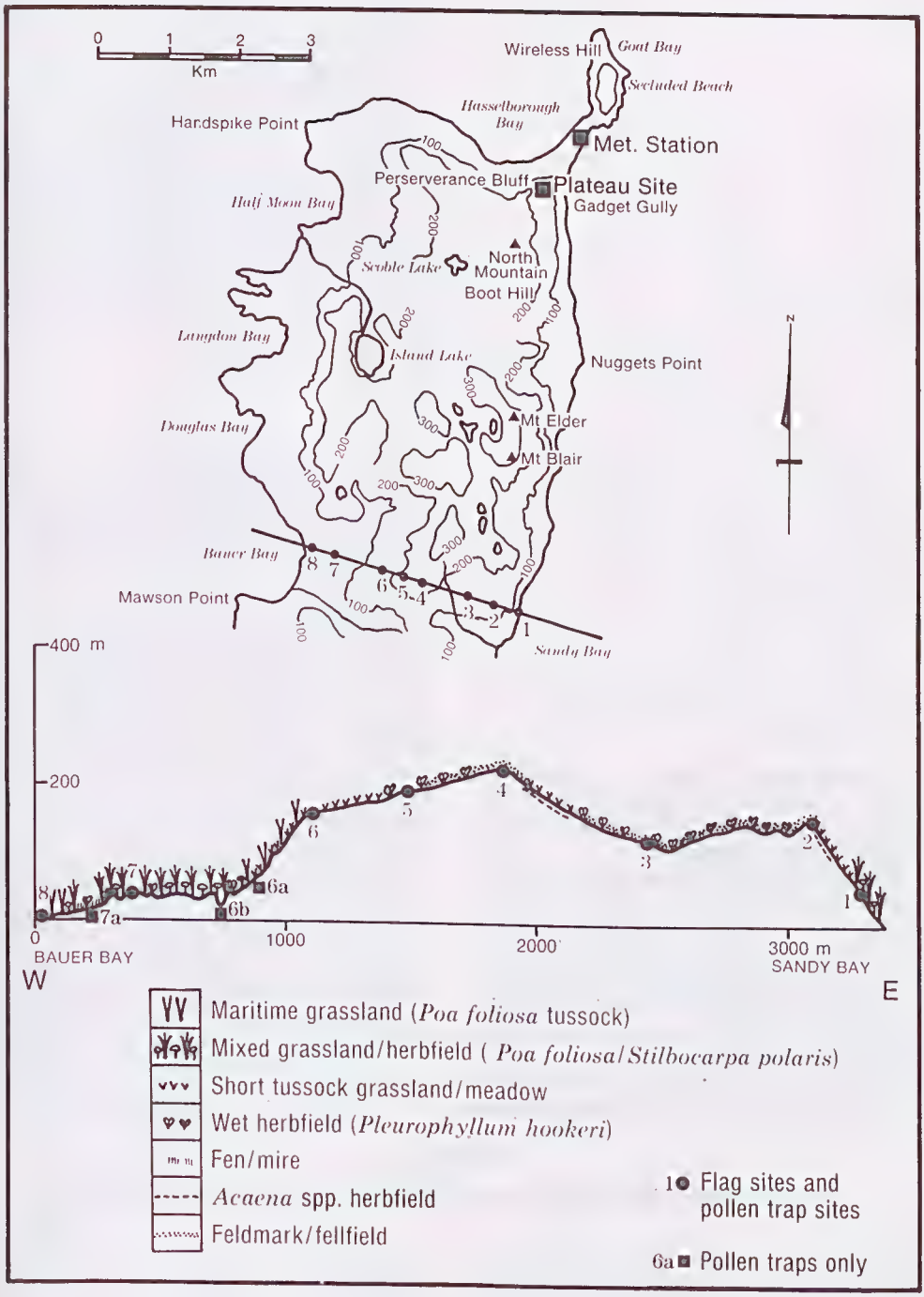

FIG. 3 — Location of TNPWS transect line and corresponding topographic cross-section with distribution of major vegetation communities. Flag station and pollen trap sites are indicated.

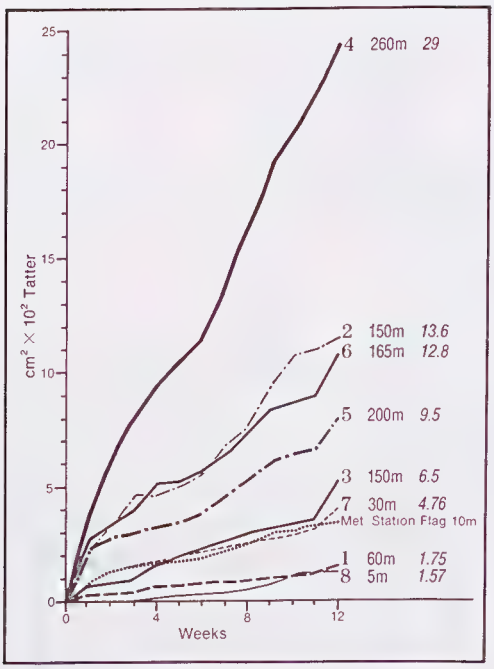

FIG. 4 — Cumulative flag tatter graph for all transect flag sites and the "control" flag at the meteorological station.

flags on graph paper. Incidence of ripping was noted but, as seen from the graph of the results (fig. 4), the comparison between sites over 12 weeks was not significantly affected.

Two further problems encountered were not frequent enough to affect results. During light and variable winds some flags became folded wet, and dried stuck in that position. The other problem occurred at Site 2, above the very steep coastal slope, when northeast winds brought updraughts and lifted the flag and spindle off its axis. The flag could not be usefully replaced under these conditions but winds from this direction would not have been frequent enough for the loss of data to affect the relative positions of the sites on the cumulative tatter graph (fig. 4).

Laboratory methods were centred around the use of a Tektronix digitising tablet for area measurement. The (white) flags were ironed, photocopied 1:1 against a black background and made ready for digitising together with the graph paper outlines. After experimentation and calibration it was decided to use software written by Dunkerley (1987) with the tablet controller in point mode. The cumulative tatter graph (fig. 4) was drawn after the area remaining at each week's end was subtracted from the measurement taken for the end of the previous week.

RESULTS

The average daily tatter rate varies greatly between sites (table 1). The most exposed sites yielded very high tatter rates: for instance nearly double that recorded for very exposed sites during winter at similar latitudes in Scotland (see Pears 1977, p.111).

As expected, the feldmark areas included the most exposed sites (4 and 2) on this traverse line. Although lower than two apparently less windy sites, Site 2 is ideally situated to receive both the expansion of the mountain gap wind across the Bauer Bay–Sandy Bay col and also the uninhibited wind flow from northeasterly to southeasterly gales, of which station records show there were two in December 1979 and one in each of November 1979 and January 1980. The next three most exposed sites, listed in order of decreasing exposure, are 6, 5 and 3. Site 6 is unsheltered on the windward site of the island. Site 5 is probably less windy for being in the boundary layer between Site 6 and the traverse divide, whereas Site 3 is comparatively sheltered from both sides. As expected from the vegetation distribution, coastal sites 1 and 8 are the most sheltered. The status of Site 8 requires explanation, however. How can such an open site on the windward side of the island be so "sheltered"?

TABLE 1

Average tatter rates (cm² per day) November 1979 — January 1980

Site	1	2	3	4	5	6	7	8	Met. Flag
November	0.5	16.9	6.46	34.1	11.4	18.2	5.7	2.4	5.7
December	1.6	10.2	4.2	25.4	7.6	8.2	2.4	0.7	2.6
January	3.16	13.75	8.8	27.7	9.5	12	3.7	1.6	3.5
Three-month average	1.75	13.6	6.5	29	9.5	12.8	4.76	1.57	3.9

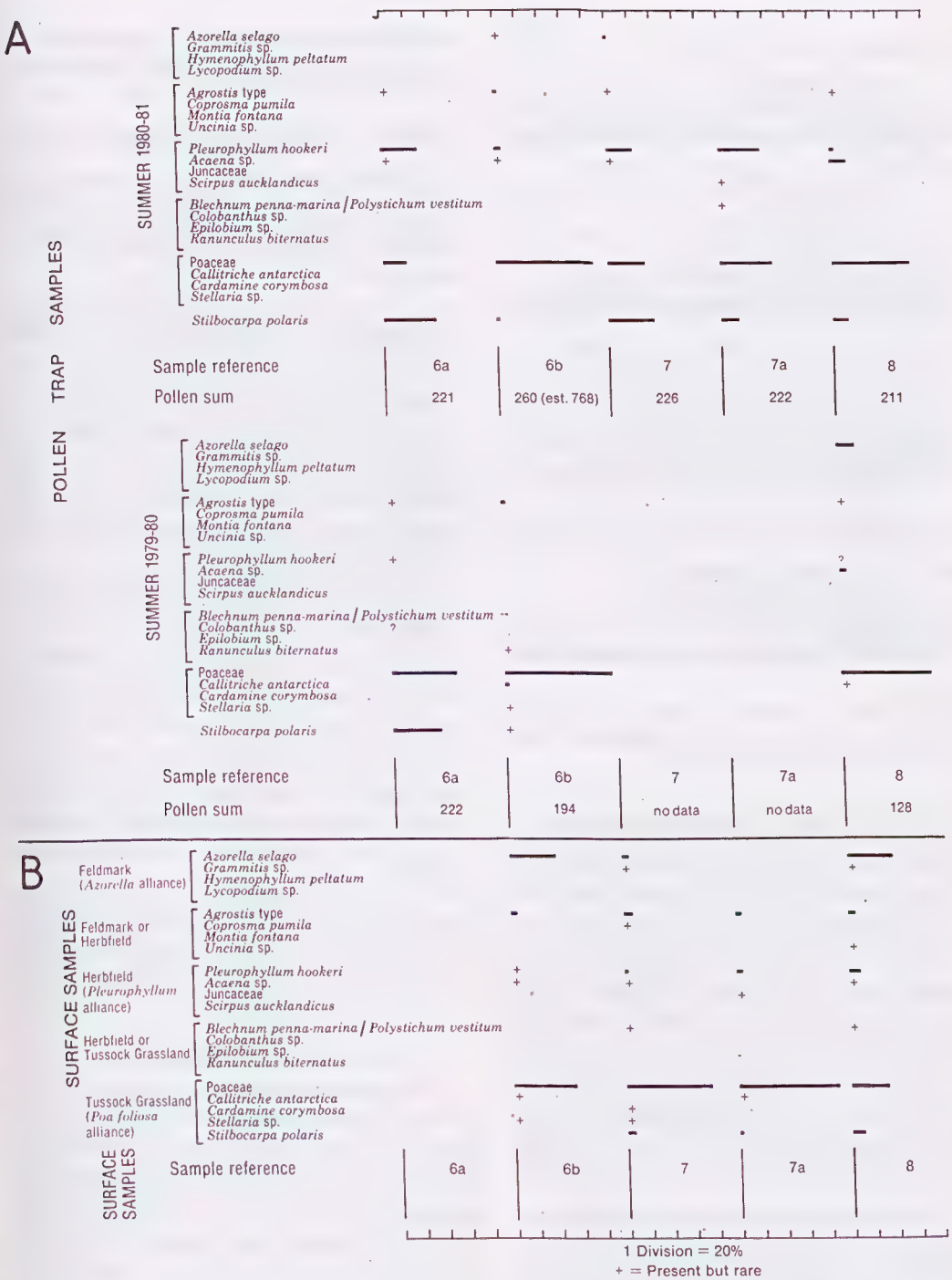

FIG. 5 — (A) Pollen trap collections from near flag sites, summers 1979–80, 1980–81. (B) Surface pollen samples from near flag sites, summer 1979–80.

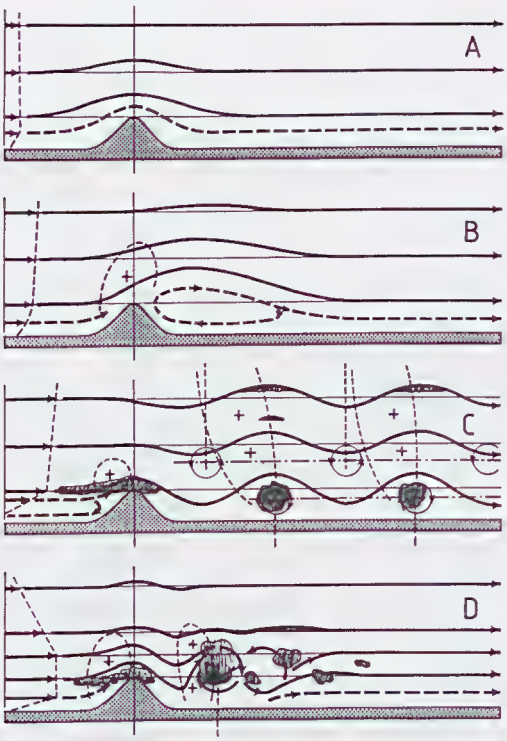

FIG. 6 — Wave streaming with crest cloud, downwind rotors and trapped rotor to windward (case C) (from Corby 1954, Barry 1981).

In the absence of detailed measurements of wind speed and direction, explanation must be sought from the analysis of the pollen trap records. Both the pollen trap and the surface sample for Site 8 for the summer of 1979–80 contain significant numbers of *Azorella selago* pollen grains (fig. 5). *Azorella* is not found in the maritime (tall tussock) grasslands but is an important component of the feldmark (see fig. 5). To explain a fallout of feldmark pollen at Site 8 against the prevailing wind one must look to the results of work elsewhere on air flow over mountain barriers. The mountain gap wind phenomenon has already been invoked to help explain exposure at Site 2, but on the west coast a trapped windward rotor must be invoked (fig. 6).

Most studies of the local air flow modification by topographic barriers are mesoscale projects with higher barriers than Macquarie Island (see Nicholls *in* Barry 1981, p.100). However, the fact that the strong and persistent winds there are frequently within 30° of perpendicular to the ridge line (e.g. see Barry 1981, p.100) suggests scope for detailed study and modelling, although the latter would be better served if a more accurate topographic map was available.

IMPLICATIONS AND CONCLUSIONS

Apart from elucidating the nature of the maritime tall tussock grassland community environment on the west coast of the island, the present study allows the following points to be made.

(1) Since emergence as a terrestrial habitat, Macquarie Island has probably always lain athwart the prevailing winds, but its effectiveness as a topographic barrier to general surface circulation must have varied with glacio-eustatic sea level changes and the balance between denudation and uplift. The effect of local wind circulations in this context must be taken into account in the interpretation of local pollen diagrams and in other palaeontological work, including debates about the origin and dispersal of species.

(2) Macquarie Island offers a very steep and abrupt topographic wind barrier across one of the strongest and most persistent surface wind circulations on earth (see Lamb 1959), and appears to facilitate local circulation patterns that are most often documented for much larger features in somewhat less windy environments. This being so, the island offers a field laboratory in miniature for the study of the effect of topographic barriers on wind circulation. There is also scope for modelling, but this would be greatly enhanced if improved topographic maps and air photographs were available.

(3) The range of Macquarie Island wind climates suggested by this work shows that any detailed studies of environment and vegetation distribution will be limited if the only wind data available are from the meteorological station.

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REFERENCES

BARRY, R.G., 1981: *MOUNTAIN WEATHER AND CLIMATE.* Methuen, London.

COPSON, G.R., 1984: Annotated atlas of the vascular flora of Macquarie Island. *ANARE Res. Notes*, 18. Antarctic Division, Department of Science and Technology.

CORBY, G.C., 1954: The airflow over mountains: a review of the state of current knowledge. *Quar. J. R. Met. Soc.*, 8: 491–521.

DE LISLE, J.F., 1965: The climate of the Auckland Islands, Campbell Island, and Macquarie Island. *N.Z. Ecol. Soc. Proc.*, 12: 37–44.

DUNKERLEY, D.L., 1987: Utility graphics programs for the Tektronics 4051 computer system. *Tech. Memo.*, 1. Geography Department, Monash University.

HNATIUK, R., 1975: Aspects of the Growth and Climate of Tussock Grassland in Montane New Guinea and Sub-Antarctic Macquarie Island. Unpublished Ph.D. thesis, A.N.U.

JENKIN, J.J., 1972: Studies of Plant Growth in a Sub-Antarctic Environment. Unpublished Ph.D. thesis, University of Melbourne.

LAMB, H.H., 1959: The southern westerlies. *Quar. J. R. Met. Soc.*, 85: 1–23.

LINES, R. & HOWELL, R.S., 1963: The use of flags to estimate the relative exposure of trial plantations. *Forestry Commission: Forest Record*, 51: 1–31.

PEARS, N., 1977: *BASIC BIOGEOGRAPHY.* Longman, London.

RUTTER, N., 1968: Tattering of flags at different sites in relation to wind and weather. *Agric. Met.*, 5: 163–181.

SALAS, M., 1983: Long-distance pollen transport over the southern Tasman Sea: evidence from Macquarie Island. *N.Z. J. Bot.*, 21: 285–292.

SEPPELT, R.D. & HUGHES, J.M.R., in press: Contrasts in vegetation patterns: Heard Island and Macquarie Island. Paper presented at the Joint SCAR/IUCN Workshop on the Biological Basis for Conservation of Sub-Antarctic Islands. Paimpont, France, 12–14 September 1966.

TAYLOR, B.W., 1955: The flora, vegetation and soils of Macquarie Island. *ANARE Rep.*, Ser. B(2).

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RABBIT DISTRIBUTION HISTORY AND RELATED LAND DISTURBANCE, MACQUARIE ISLAND

by J.J. Scott

(with one table and three text-figures)

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Rabbits have been a part of the Macquarie Island environment since their introduction in the late nineteenth century by sealing gangs. Although sufficient documentation exists to show that their detrimental effects on the native fauna and flora have been substantial, their status as agents of erosion is not clear. From evidence presented on the known history of rabbit distribution, it appears that their contribution to land instability has been overrated by some research workers. This view is supported by discussion of the major initiating mechanisms of landslips and the role of earthquakes in erosion processes, especially in close proximity to major fault lines. The overall effect of rabbits on the Macquarie Island environment, including vegetation damage and their localised contribution to erosion, nevertheless warrants a continuation of the present eradication campaign. In this regard, the protection of the few remaining coastal areas which have not yet been invaded to any extent should have high priority.

Key Words: rabbits, rabbit distribution history, erosion, land disturbance, vegetation damage, Macquarie Island.

INTRODUCTION

Rabbits were introduced to Macquarie Island as a source of food by nineteenth-century sealing gangs, with their first recorded introduction being 1878 (Cumpston 1968). In a similar way they were introduced to other subantarctic islands, and also islands all around Australia, by the crews of early sailing ships, against the possibility of shipwreck (Armstrong 1982). Documentation exists to show that in most cases the rabbits multiplied and had a significant effect on these island environments, few of which had previously supported any terrestrial vertebrate herbivores (e.g. Holdgate & Wace 1961, Edmonds *et al.* 1976, Norman 1967, Fullagar 1978, Armstrong 1982).

Sufficient documentation is available for Macquarie Island to show that the effects of rabbits on native fauna and flora have been substantial (Brothers & Copson 1988). Their effect on land stability and the erosion regime has been less clear, and has been a matter of controversy in recent years, as outlined below. It is the purpose of this paper to add to the debate by examining available information on rabbit distribution history and commenting further on their contribution to land disturbance.

RABBIT DISTRIBUTION HISTORY AND RELATED ASPECTS

When Macquarie Island is mentioned in literature reviewing introduced fauna and flora on islands, erosion and vegetation damage is usually noted as being severe (Holdgate & Wace 1961, Holdgate 1967, Moore 1983). In each case the discussion has been based on the published work of B.W. Taylor, who spent a year on the island in 1950–51 (Taylor 1955), and of A.B. Costin and D.M. Moore, who visited the island briefly in 1958 (Costin & Moore 1960). It is likely, however, that these researchers saw the island during particularly severe periods of grazing damage and, in the case of Costin and Moore, not necessarily the whole island. Both before and after the two visits the intensity and location of grazing seem to have varied quite markedly over time, as have its effects.

This point is illustrated by table 1 (pp. 264–266, which summarises available information on rabbit distribution for the 100 years between the first recorded introduction in 1878 and the introduction of myxomatosis in late 1978.

Reports on rabbit occurrence and distribution are somewhat scattered until 1974. Prior to Taylor's period on the island in 1950, they are purely incidental and mainly contained in historical accounts collected by J. Cumpston in his detailed history of the island (Cumpston 1968). From 1974

to 1978, an intensive rabbit ecology research programme was undertaken by the Tasmanian National Parks and Wildlife Service (TNPWS) (Skira 1978, 1980, Copson *et al.* 1981, Skira *et al.* 1982). In 1978, myxomatosis was introduced by the Service as a control measure. Over the next two to three years, a marked decrease in rabbit numbers (over 50% killed) was evident in the central section of the island and in some areas further south (Brothers *et al.* 1982). Regular monitoring of rabbit numbers and releases of virus have been continuing (G. Copson, pers. comm.).

Despite the patchy nature of the information in table 1, a number of apparent trends are indicated. Rabbits were reported to be numerous at the north end for about ten years after 1878 (Cumpston 1968), with no reports from the south end, except for a negative report at Lusitania Bay in 1889 (this being the most commonly visited location south of Sandy Bay). However, in 1894 rabbits were reported as being numerous in the southeast (presumably the Lusitania Bay area) and absent in the north (Cumpston 1968).

From 1894 until at least 1919, the rabbit population in the north appeared to fluctuate markedly, although rabbits seem to have remained common around Lusitania Bay (Cumpston 1968, Mawson 1915, 1943, Sobey *et al.* 1973, Costin & Moore 1960). Few data are available between 1919 and 1948 (G. Copson, pers. comm.). In 1923, a party from the Sir James Ross Clark whaling expedition found no rabbits at the north end (Villiers 1949), and a visit by BANZARE personnel, in December 1930, reported rabbits as being plentiful around Lusitania Bay (Falla 1937). From 1948 until probably the early 1960's, rabbits were reported to be scarce in the north, and were mainly concentrated south of Sandy Bay–Bauer Bay, with Taylor noting a large increase in population, to "plague proportions", in and just north of the Sandy Bay area in 1950 (Taylor 1955, p.95).

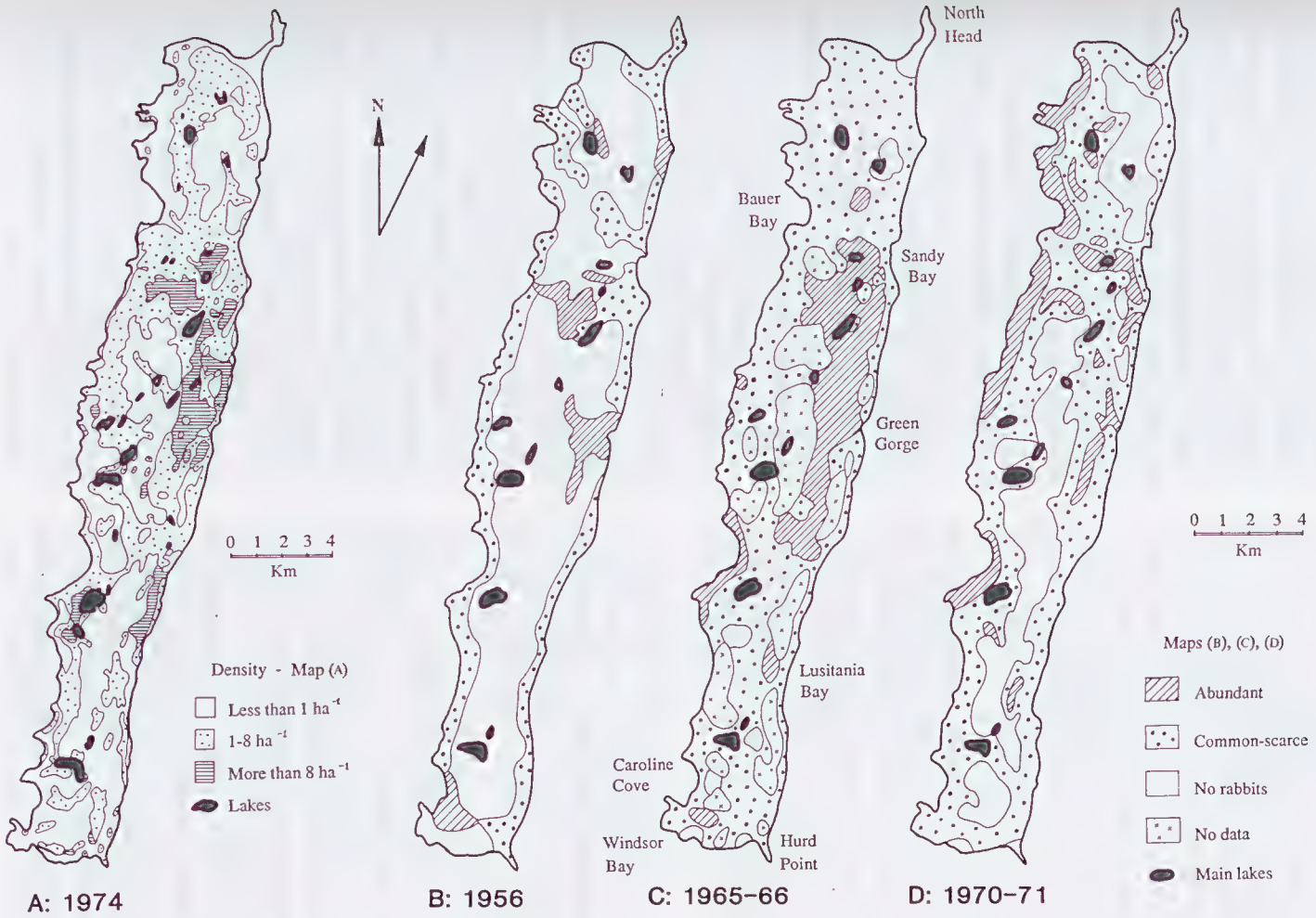
During a series of yearly December visits to the Island from the early to mid-1960's, a marked increase in rabbit numbers north of Sandy and Bauer Bays was noted by Ashton, especially around the Island Lake–Scoble Lake area (D. Ashton, pers. comm.). A report to the Australian Conservation Foundation, prepared by the CSIRO Division of Wildlife Research in 1971, indicated that rabbits had spread north again after about 1965 (Fennessey 1971). Rabbit numbers were estimated at 50 000 in 1956 and 150 000 in 1965–66 (Sobey *et al.* 1973). Mapped distributions for these years indicate that the major increase occurred in the central area of the island (fig. 1), as it did during the "build-up" to the next major population peak in 1977–78 (see below).

Skira (1979) estimated numbers at 50 000 in 1974–75, and noted that different counting methods used by the different studies could have given an erroneously high figure for the 1965–66 estimate of Sobey *et al.* (1973). However, it is of interest that the total rabbit population was estimated at around 150 000 in 1977–78, the peak breeding year experienced during the TNPWS rabbit ecology programme (Copson *et al.* 1981). Although rabbit numbers increased markedly between 1974 and 1977–78, their distribution remained similar to that mapped in 1974 by Brothers *et al.* (1982) and shown in figure 1.

From these records, and from detailed studies during the TNPWS rabbit ecology programme, it can be seen that rapid fluctuations have occurred in the rabbit population on the island (prior to commencement of the control programme). Selkirk *et al.* (1983) suggested a general population pattern consistent with that of introduced species elsewhere, i.e. low for a long period after introduction, followed by a period of rapid expansion to a maximum perhaps beyond the habitat's capacity to support it, then a fall in numbers to a lower level in balance with habitat capacity.

Within this general framework, smaller scale fluctuations may occur. Contributing factors may include local overgrazing and subsequent movement of large numbers of rabbits elsewhere (Taylor 1955, Sobey *et al.* 1973), and possibly local differences in weather. It has been suggested, however, that Taylor's interpretation of mass movements of rabbits is incorrect, and that the more likely explanation of large numbers of rabbits causing substantial damage in new areas is that the proportional increase in numbers is greater in low density areas than in high density areas during a good breeding season, possibly due to greater food availability there (G. Copson, pers. comm.). This occurred, for example, in the 1977–78 season, when the highest summer counts in the Red River valley, a high density area, barely doubled, whereas counts in a low density area south of Bauer Bay increased fivefold (G. Copson, pers. comm.). It has also been noted that seasonal weather changes, such as an extended period of dry weather, allow a high survival rate of young rabbits, leading to a rapid increase in numbers, especially in marginal breeding areas such as the edges of herbfield habitats (Copson *et al.* 1981).

A number of field observations have noted substantial differences in the rainfall regime occurring in different parts of the island at any one time



Sources: Map (A) Brothers *et al.* (1982) Maps (B), (C), (D) After Sobey *et al.* (1973)

FIG. 1 — Available maps of rabbit distribution and abundance.

(G. Copson, pers. comm.). Flooding of burrows by rising water-table levels depends on rainfall: long-term variations from average rainfall appear to have greater effects on the rabbit population as a whole than short-term variations (Copson *et al.* 1981). The uniform annual distribution of precipitation means that burrow flooding can occur at any time, in both normal and marginal burrowing habitats. This is relevant when considering some of the records in table 1. Taylor's 1950 observations followed eleven of the driest months on record, making it likely that he witnessed more severe overall rabbit damage than usual (Copson 1984). Skira (1984) attributes the increase in overall population (from 50 000 in 1974 to 150 000 in 1978) to several dry summers.

Studies of distribution and abundance during the TNPWS rabbit ecology programme found that fluctuations in rabbit numbers occur both seasonally and annually. On a seasonal basis, maximum numbers occur in December and January, corresponding with a buildup of young rabbits from peak breeding months of October and November (Copson *et al.* 1981). This also coincides with the period of accelerated plant growth due to increased photoperiod and slightly increased temperatures (Shipp *et al.* 1963, Jenkin & Ashton 1970, Skira 1978).

It seems likely that annual population fluctuations are due to changes in weather for the island as a whole rather than annual predation or overgrazing which, although affecting populations locally, are unlikely to affect the whole population simultaneously (Copson *et al.* 1981). These factors may account for some of the differences in records noted in table 1.

Severe grazing damage was documented in 1958 at the south end of the island by Costin & Moore (1960). Selkirk *et al.* (1983) comment that the dense rabbit populations which occur at different times in different places on the island are likely to coincide with maximal damage to the local environment, and suggest that Costin & Moore's observations may have been made soon after such a period at Hurd Point. The low population estimate for 1956 by Sobey *et al.* (1973), along with their distribution map for 1956, indicating a concentration of rabbits in the upper Caroline Cove area (see fig. 1), supports the view that the damage noted by Costin & Moore was localised. The severe accelerated erosion, which they predicted on the basis of their extensive experience in alpine Australian environments, has not occurred, as subsequent investigation and rephotographing of their study sites has shown (Selkirk *et al.* 1983).

Locally, rabbit distribution is governed by vegetation type and associated habitat factors. The available maps of rabbit distribution and abundance (fig. 1), although representing limited time periods, can be compared to the partly superseded vegetation map of Taylor (1955), shown in figure 2, and general correlations noted. Rabbits most commonly inhabit herbfield vegetation (Copson *et al.* 1981). This is taken to include short tussock grassland vegetation (Selkirk *et al.* 1983) or meadow grassland (Seppelt & Hughes in press), represented in most cases by long-grazed forms of either *Poa foliosa* tall tussock or herbfield characterised by *Pleurophyllum hookeri* (Seppelt *et al.* 1984). The latter two categories are shown in figure 2. It must be noted that Taylor's vegetation map does not include a category for short tussock grassland/meadow grassland, as he assumed it to be a result of long-term intense rabbit grazing and therefore not a "natural" vegetation type (Taylor 1955). This means that it is not possible to ascertain from the map the actual extent of this vegetation type at the time, nor the degree of change since. The vegetation map is urgently in need of revision before it can be used as an effective management tool. This in turn requires a full-coverage, aerial photography programme to be undertaken.

The densely populated rabbit areas in the central part of the island and on the east coast (fig. 1) are shown to be vegetated with *Poa foliosa* tall tussock (fig. 2). In actual fact, the vegetation type is mainly short tussock grassland/meadow grassland. The same situation applies also on the 1979–81 maps of myxomatosis distribution and intensity presented by Brothers *et al.* (1982), where high success rate of myxomatosis can be equated with high concentration of rabbits. In all cases, the areas of lowest rabbit density mainly occur at the north end of the island or at the far southern end. Low densities in the north coincide mainly with feldmark and wet coastal terraces, although high rabbit densities may occur in pockets of suitable habitat (G. Copson, pers. comm.). At the far southern end, low densities coincide with areas of feldmark or the densely clad slopes of *Poa foliosa*.

From the above information, it is possible to speculate on the way in which rabbits have spread over the island since their introduction at the northern end. The pattern of invasion appears to have occurred either along the mid-altitude slopes of the plateau or along the wide coastal terrace on the northwestern half of the island, encroaching on the tall tussock slopes and inland valleys from both the terrace below and the plateau above. At the southern end of the island, where coastal terraces

are narrow to non-existent, rabbits have encroached on the slopes from the plateau above, where populations exist in favourable herbfield patches, and they are still doing so (R. Gould, TNPWS, pers. comm.). The current vegetation of the steep far-south coastal slopes, for example around Hurd Point and Windsor Bay, is composed of mature *Poa foliosa* with large, leaning tussock pedestals, indicating undisturbed vegetation of a considerable age (Ashton 1965, Taylor 1955). From all indications, these slopes support vegetation which either has not been grazed for a very long time or (more likely) has not been grazed at all. Along with the steep slopes immediately to the north of Caroline Cove, this is the only reasonably extensive area of costal slope vegetation remaining in this condition on the island.

The character of these slopes and the coast below is noticeably different from other parts of the island. Another contributing factor is the general absence of the introduced grass *Poa annua* at sea level, for example on the southwest coast at Windsor Bay. *Poa annua*, a naturalised alien, has become widely distributed on Macquarie Island (Jenkin *et al.* 1981, Copson 1984), and assumes a major role in cycles of revegetation in seal wallow areas on many parts of the coast (Gillham 1961). Its spread on the island is aided by rabbits and is almost invariably associated with rabbit presence, although the reverse is not necessarily so (Scott 1985).

Since it is a major objective of Macquarie Island management policies to restore the island ecosystems as far as possible to their natural state, it is disturbing that, in 1986, one of the major concentrations of rabbits was at the south end of the island (R. Gould, pers. comm.), where myxomatosis is only now starting to become established and *Poa foliosa* tall tussock vegetation, for example on the steep slopes above Hurd point, is continuing to be eaten and replaced by short tussock grassland/meadow grassland. This was one of the areas where success was not achieved during the initial years of virus introduction and where difficulties are still being experienced. The main reasons appear to be irregular distribution and slow spread of rabbit fleas (G. Copson, pers. comm.).

On the basis of the above, it would appear to be of high priority that this area is protected from further invasion by rabbits. The area is already restricted for human visitors during the summer period, due to other conservation priorities (see Brothers & Copson, this volume).

FIG. 2 — Vegetation map — main structural formations.

EROSION AND RABBITS — SOME COMMENTS

Macquarie Island is subject to a high level of erosional activity (Griffin 1980). The extent to which various mechanisms, including biotic factors, initiate and influence erosion on the island has been debated by various researchers. These include Blake, in Mawson (1943), Taylor (1955), Costin & Moore (1960), Jenkin (1977), Ledingham (1978), Griffin (1980), Selkirk *et al.* (1983), Scott (1983) and Scott (1985). The main focus for this debate, since Costin & Moore's 1960 publication, has been on the relative contribution by feral rabbits to the erosion regime.

It is not intended to cover the debate here, but instead to make several additional comments which support the view that, in the general long-term picture, rabbits may not be a major contributing factor to erosion, as initially supposed by workers such as Taylor (1955) and Costin & Moore (1960). The information presented above on rabbit distribution history also supports this view.

Landslips

It is likely that landslips, common phenomena on Macquarie Island, are initiated by seismic events and unusually heavy rainfall, acting either alone or in combination (Ledingham 1978, Griffin 1980, Scott 1984, G. Copson, pers. comm.). Both mechanisms are recognised as major causes of landslides generally (Terzaghi 1950). During a large earthquake in February 1980, landslips occurred on both grazed and ungrazed slopes, mainly in the form of rockfalls and debris slides from outcrops, with shearing of tall tussock vegetation and upper peat layers on the slopes below the outcrops (Scott 1985). The occurrence of landslips, in the form of mudflows with associated debris slides immediately following unusually heavy rain, has been noted on a number of occasions, on both rabbit-grazed slopes and ungrazed slopes (Taylor 1955, Ledingham 1978, Griffin 1980, G. Copson, pers. comm., J. Jenkin, pers. comm.). In each case, peat becomes locally saturated, resulting in collapse of the mantle downslope.

Relative importance of the two major landslip-initiating factors appears to depend on drainage conditions, local topography, presence of outcrops on the slope, proximity to fault lines and possible maturity of tall tussock vegetation, if present. Taylor (1955) considers that heavy rainfall is particularly important in initiating landslips in mature tall tussock communities where continual vegetation growth has allowed a deep peat layer to develop. The inherent "instability" of mature, leaning *Poa foliosa* tussocks on steep slopes has been noted by Taylor (1955), Jenkin (1977) and Scott (1984). A similar phenomenon was observed on Gough Island by Wace (1961), on steep slopes vegetated with fernbush. Rapid peat accumulation in a moist environment, with the living rhizomes of the main fern species confined to the upper half-metre of peat, has lead to frequent peatslips. Similar cyclic processes were also noted in tussock grassland on the island, which lacks introduced herbivores (Wace 1961).

Although rabbits do not appear to act as major initiators of landslips on Macquarie Island, they can play a part in the process, as heavy grazing contributes to a rise in the water table (Copson 1984) and hence allows more rapid waterlogging. This has been observed on steep slopes, in relation to an increased flooding frequency of ground-nesting petrel burrows after removal of tall tussock vegetation (N. Brothers, pers. comm.). Rabbits also contribute to reslipping of material on revegetating landslip surfaces (Scott 1983). Since rabbits seem to avoid both tall grass and moist sticky peat, evidence of their presence is sometimes more easily found on old landslip surfaces, where the height of vegetation is lower and the soil is thin and gravelly, than on the surrounding unslipped slopes. Scratching and digging after the vegetation cover is removed can then lead to reslipping. This phenomenon is clearly seen on slopes which are only just being invaded by rabbits, such as in the far south of the island (Scott 1985).

It has been suggested that rabbits on Macquarie Island may have an indirect role in weakening the cohesion of surface peat through removal of deep-rooted dominent species (Costin & Moore 1960, Jenkin 1977). Removal by grazing of short, non-pedestalled *Poa foliosa* on revegetating landslips, and the subsequent death of the dense net of underground rhizomes (as in Ashton 1965), may well have a more marked effect on stability than removal of mature, pedestalled *Poa foliosa* on the surrounding slopes, where the living rhizomes are confined to the top of the pedestals (Ashton 1965). The extent to which slope stability, in the latter situation, may actually be increasedby removal of *Poa foliosa* by rabbits, is uncertain.

Seismic Effects

Macquarie Island's geological setting of strong control by faulting in a seismically active environment suggests that overall uplift and distribution of lineaments (mainly fault lines) have had an important influence on the evolution of the island's landforms (Ledingham & Peterson 1984). The island is almost continually active from a seismic point of view (see Jones & McCue, this volume) and slope stability is bound to reflect this fact. When the locations of the major erosion events observed after the large earthquake in February 1980 (mapped by Ledingham (1981) and comprising peat slips, rockfalls and peat cracks) are compared with the locations of the main lineaments mapped by Ledingham & Peterson (1984) (see fig. 3), a high visual correlation becomes evident. The frequency of erosion features along these lineaments is high, in any case, exacerbated

by the friable metamorphosed nature of rocks in the fault zones. It is manifested in numerous scree slopes and landslip scars on steep slopes, and by slumping and cracking of peat and numerous bare peat patches on shallower slopes (Ledingham 1978, 1981, Scott 1984 and unpublished).

Examples of extensive slope erosion can be seen on the west-facing slopes of Red River Valley and Sawyer Creek Valley, the east-facing (coastal) slopes from Nuggets Point to First Gully, and the west-facing slopes of Wireless Hill (south of North Head), all of which are on major fault lines along the east coast (fig. 3). It would appear that earthquakes must have had a larger influence than previously suggested in initiating and maintaining erosion on steep slopes, such as these, and also on the shallower mid-altitude plateau slopes.

SUMMARY

The points discussed above can be summarised in terms of their relevance to management of the Macquarie Island environment, as follows:

(1) The overall effect of rabbits on the Macquarie Island environment, especially on native flora and fauna, justifies continuation of the current eradication campaign. Although not a major initiating factor, as formerly proposed, rabbits contribute to the erosion regime in a localised context, which supports the argument for their eradication.

(2) The available vegetation map of the island, compiled in 1950–51, is out of date and in urgent need of revision before it can be used as an effective management tool. This, in turn, requires a full-coverage, colour aerial photography programme to be undertaken.

(3) On the basis of available information on the history of rabbit distribution on the island, inferred patterns of rabbit invasion and the nature of the present vegetation, it can be stated that coastal slopes in the far southwestern corner have not been grazed by rabbits to an extent where vegetation changes have occurred. This, therefore, represents the only reasonably extensive area of coastal slope vegetation on the island remaining in this condition. In view of the objectives of Macquarie Island management policies, it is considered to be of high priority that this area is protected from further invasion by rabbits.

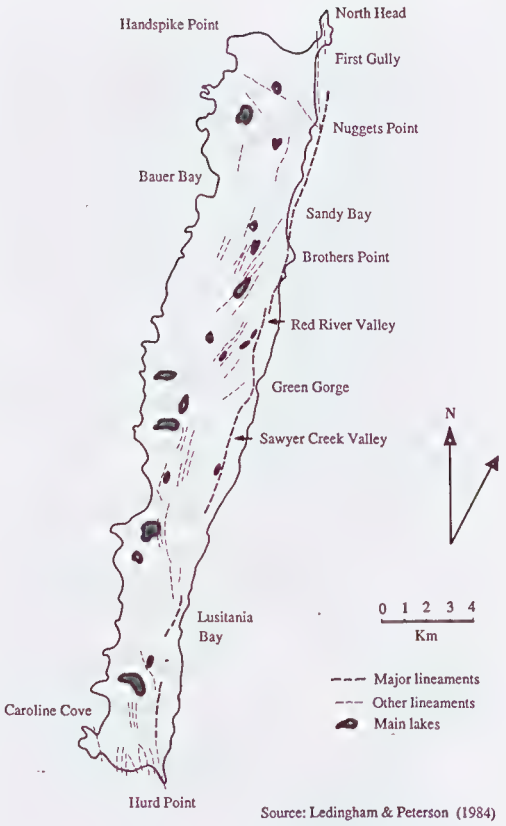


FIG. 3 — Macquarie Island — main structural lineaments.

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REFERENCES

ARMSTRONG, P., 1982: Rabbits (*Oryctolagus cuniculus*) on islands: a case-study of successful colonisation. *J. Biogeogr.*, 9: 353–362.

ASHTON, D.H., 1965: Regeneration pattern of *Poa foliosa* Hook. f. on Macquarie Island. *Proc. R. Soc. Vict.*, 79: 215–233.

BROTHERS, N.P. & COPSON, G.R., 1988: Macquarie Island flora and fauna mamagement — interpreting progress and predictions for the future. *Pap. Proc. R. Soc. Tasm.* 122(1): 129–135.

BROTHERS, N.P., EBERHARD, I.E., COPSON, G.R. & SKIRA, I.J., 1982: Control of rabbits on Macquarie Island by myxomatosis. *Aust. Wildl. Res.*, 9: 477–485.

COPSON, G.R., 1984: An annotated atlas of the vascular flora of Macquarie Island. *ANARE Res. Notes*, 18. Antarctic Division, Department of Science and Technology.

COPSON, G.R., BROTHERS, N.P. & SKIRA, I.J., 1981: Distribution and abundance of the rabbit, *Oryctolagus cuniculus* (L.) at subantarctic Macquarie Island. *Aust. Wildl. Res.*, 8: 597–611.

COSTIN, A.B. & MOORE, D.M., 1960: The effects of rabbit grazing on the grasslands of Macquarie Island. *J. Ecol.*, 48: 729–732.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser.A(1). Antarctic Division, Department of External Affairs.

EDMONDS, J.W., NOLAN, I.F., SHEPHERD, R.C.H., BACKHOLER, J.R. & JACKSON, R., 1976: Rabbits on Gippsland Islands. *Vict. Nat.*, 93: 110–112.

FALLA, R.A., 1937: Birds. *BANZARE Rep.*, Ser. B(2): 288 pp.

FENNESSEY, B.V., 1971: Rabbits on Macquarie Island. Comments by the Division of Wililife Research, CSIRO, Canberra, for the Scientific Committee of the Australian Conservation Foundation, 30/7/71 (typescript): 12 pp.

FULLAGAR, P.J., 1978: *REPORT ON THE RABBITS ON PHILIP ISLAND, NORFOLK ISLAND.* Division of Wilflife Research, CSIRO, Canberra.

GILLHAM, M.E., 1961: Modification of subantarctic flora on Macquarie island by seabirds and sea elephants. *Proc. R. Soc. Vict.*, 74: 1–12.

GRIFFIN, B.J., 1980: Erosion and rabbits on Macquarie Island: some comments. *Pap. Proc. R. Soc. Tasm.*, 114: 81–83.

HOLDGATE, M.W., 1967: The influence of introduced species on the ecosystems of temperate oceanic islands. *Publs IUCN*, 9: 151–176.

HOLDGATE, M.W. & WACE N.M., 1961: The influence of man on the floras and faunas of southern islands. *Polar Rec.*, 10: 475–493.

JENKIN, J.F., 1977: The effects of rabbits on Macquarie Island. Unpublished report to TNPWS, Hobart.

JENKIN, J.F. & ASHTON, D.H., 1970: Productivity studies on Macquarie Island vegetation. *In* Holdgate, M.W. (Ed.): *ANTARCTIC ECOLOGY.* Academic Press, London: 851–863.

JENKIN, J.F., JOHNSTONE, G.W. & COPSON, G.R., 1981: Introduced animal and plant species on Macquarie Island. *Colloque sur les ecosystemes Subantarctiques.* CNFRA no.51. Paimpont, France.

JONES, T.D. & McCUE, K.F., 1988: The seismicity and tectonics of the Macquarie Ridge. *Pap. Proc. R. Soc. Tasm.*, 122(1): 51–57.

LAW, P.G. & BURSTALL, T., 1956: Macquarie Island. *ANARE Interim Rep.*, 14. Antarctic Division, Melbourne.

LEDINGHAM, R.B., 1978: Report on some aspects of erosion on Macquarie Island 1977. *Antarct. Div. Tech. Mem.*, 72. Antarctic Division, Melbourne.

LEDINGHAM, R.B., 1981: Macquarie shakes again. *Aurora*, 2: 6–8.

LEDINGHAMR.B. & PETERSON, J.A., 1984: Raised beach deposits and the distribution of structural lineaments on Macquarie Island. *Pap. Proc. R. Soc. Tasm.*, 118: 223–235.

MAWSON, D., 1915: *HOME OF THE BLIZZARD.* Vol.2. Lippincott, Philadelphia. Chapter 26 (account of Macquarie Island written by G.F. Ainsworth).

MAWSON D., 1943: Macquarie Island: its geography and geology. *AAE Sci. Rep.*, Ser. A(5).

MOORE, D.M., 1983: Human impact on island vegetation. *In* Holzner, M.J.A., Werger, M.J.A. & Ikensima, I. (Eds): *MAN'S IMPACT ON VEGETATION.* Junk, The Hague: 237–246.

NORMAN, F., 1967: The interactions of plants and animals on Rabbit Island, Wilson's Promontory, Victoria. *Proc. R. Soc. Vict.*, 80(2): 193–200.

SCOTT, J.H., 1882: Macquarie Island. *Trans. R. Soc. N.Z.*, 15: 484–493.

SCOTT, J.J., 1983: Landslip revegetation and rabbits, subantarctic Macquarie Island. *Proc. Ecol. Soc. Aust.*, 12: 170–171.

SCOTT, J.J., 1984: Landslip-hunting on Macquarie Island. *Aurora*, 11: 12–15.

SCOTT, J.J., 1985: Effects of feral rabbits on the revegetation of disturbed coastal slope sites, Macquarie Island. Unpublished M.A. thesis, Monash University, Melbourne.

SELKIRK, P.M., COSTIN, A.B., SEPPELT, R.D. & SCOTT, J.J., 1983: Rabbits, vegetation and erosion on Macquarie Island. *Proc. Linn. Soc. N.S.W.*, 106: 337–346.

SEPPELT, R.D., COPSON, G.R. & BROWN, M.J., 1984: Vascular flora and vegetation of Macquarie Island. *Tasm. Nat.*, 78: 7–12.

SEPPELT, R.D. & HUGHES, J.M.R., in press: Contrasts in vegetation patterns: Heard Island and Macquarie Island. *2me Colloque sur les ecosystemes Subantarctiques*, 8–11 Sept. 1986. Paimpont, France.

SHIPP, E., KEITH, K., HUGHES, R.L. & MYERS, K., 1963: Reproduction in a free-living population of domestic rabbits, *Oryctolagus cuniculus* (L.) on a sub-Antarctic island. *Nature*, 200: 858–860.

SKIRA, I.J., 1978: Reproduction of the rabbit, *Oryctolagus cuniculus* (L.) on Macquarie Island, subantarctic. *Aust. Wildl. Res.*, 5: 317–326.

SKIRA, I.J., 1979: Studies of the rabbit population on Macquarie Island. Unpublished M.Sc. thesis, University of Tasmania.

SKIRA, I.J., 1980: Some population parameters and seasonal changes in the weights of internal organs of rabbits, *Oryctolagus cuniculus* (L.), at Macquarie Island. *Aust. Wildl. Res.*, 7: 235–245.

SKIRA, I.J., 1984: The rabbit on Macquarie Island. *Tasm. Nat.*, 79: 14–15.

SKIRA, I.J., BROTHERS, N.P. & COPSON, G.R., 1982: Coat colour and fitness of rabbits on Macquarie Island. *Aust. Wildl. Res.*, 9: 121–123.

SOBEY, W.R., ADAMS, K.M., JOHNSTON, G.C., GOULD, L.R., SIMPSON, K.N.G. & KEITH, K., 1973: Macquarie Island: the introduction of the European rabbit flea *Spilopsyllus cuniculi* (Dale) as a possible vector for myxomatosis. *J. Hyg.*, 71: 299–308.

TAYLOR, B.W., 1955: The flora, vegetation and soils of Macquarie Island. *ANARE Rep.*, Ser. B(2): 19. Antarctic Division.

TERZAGHI, K., 1950: Mechanisms of landslides. *Geol. Soc. Am. Eng. Geol.* (Berkeley) Nov. 1950: 83–123.

VILLIERS, A., 1949; *WHALERS OF THE MIDNIGHT SUN.* Angus and Robertson.

WACE, N.M., 1961: The vegetation of Gough Island. *Ecol. Monogr.*, 31: 337–367.

WARHAM, J., 1967: The white-headed petrel *Pterodroma lessoni* at Macquarie island. *Emu*, 67: 1–22.

(accepted 15 September 1987)

TABLE 1

Summary of Known Rabbit Distribution History, Macquarie Island, 1878–1978

Date	North End*	South End**	General	Source
1878	Rabbits introduced, NE Harbour (Buckles Bay); "numbers running about" after 7 months			Cumpston (1968): 119
1880	"Swarms at the north end"			Scott (1882): 492
1882	Numerous at north end			Cumpston (1968)
1884	Numerous at north end, including Sandy Bay — counted in their thousands			Cumpston (1968)
1889	At north end and Sandy Bay	Not at Lusitania		Cumpston (1968)
1890			Any amount of rabbits	Cumpston (1968)
1891			Numerous	Cumpston (1968)
1894	Not in north, owing to cats	Numerous in the southeast		Cumpston (1968)
1901		At Lusitania and on plateau above		Cumpston (1968)
1905–1906	Common at Nuggets Point area			Cumpston (1968)
1909–1910	None at Nuggets Point area			Cumpston (1968)
1911–1914	Few at north end; some west of Mt Elder 1912	Gradually withdrawn to southern part of island, mainly on east coast; numerous at Lusitania; severely grazed area only extended 3 miles north of Lusitania	Not seen on west coast	Cumpston (1968) Mawson (1915) Mawson (1943)
1915		Plentiful at Lusitania		Cumpston (1968)
1918	Common at Nuggets Point area			Cumpston (1968)
1923	None at Nuggets or North Head/Isthmus area			Cumpston (1968)

1929		Rabbits collected at Lusitania		Cumpston (1968)
1948		Largest concentration at Lusitania–Waterfall Bay		Taylor (1955)
1949		Largest concentration at Green Gorge		Taylor (1955)
1950	Isolated pockets of grazing e.g. south of Island Lake and Mt Elder area; "grazing line" extended north of Sandy Bay 800 m; plague proportions in Sandy Bay area	Whole island south of Sandy-Bauer severely grazed; abundant in Brothers Valley — very heavily grazed		Taylor (1955) Law & Burstall (1956)
1951	Numbers dropped to normal at Sandy Bay	Largest concentration at Flat Creek		Taylor (1955)
1954		Brothers Valley complete regenerated		Law & Burstall (1956)
early 1950's	Occasional sightings; have been observed at North Head	Concentrated slightly south of Sandy Bay and Green Gorge; have not been observed at Hurd Pt		Cumpston (1968)
1956	Abundant, Nuggets and Island Lake; sparse around coast, including North Head; common Mawson Pt	Abundant Flat Ck, Green Gorge area, Caroline area; common on parts of W and E coasts and plateau above Hurd; sparse on rest of coast; none south coast	Total numbers estimated 50 000; mainly occur around coast and several inland locations; see fig. 1	Sobey et al. (1973)
1958	No rabbits on North Head	Severe grazing noted on upper slopes and plateau between Hurd and Caroline		Costin & Moore (1960)
1960			Obvious spread of vegetation destruction and erosion including removal of debris by willy-willies	Warham (1967)
1961–late 1960's	Recent increase in north end, especially Island Lake-Scoble Lake		Apparent rapid spread of rabbits since 1965, now extending from one end of island to the other	Fennessey (1971), D. Ashton (pers. comm.)

Date	North End*	South End**	General	Source
1965–1966	Occur sparsely over most areas; common Bauer–Sandy, Square Lake, North Mt; abundant inland of Sandy; none on North Head	Abundant between Sandy Bay–Flat Ck–Red River–Jessie Niccol Ck, Sandell Bay, Lusitania Bay, Caroline; common on outskirts of these areas, Major Lake, plateau N of Hurd; sparse around most of remaining coast, including S	Total numbers estimated 150 000; occur over most of island; see fig. 1	Sobey et al. (1973)
1970–1971	Abundant NW coast between Bauer and Handspike; Island Lake; Perseverance Bluff; and between Bauer–Sandy; common on NW coastal slopes; sparse NE coastal slopes and North Head	Abundant central west coast, Sandell Bay, Sawyer Ck, Green Gorge, Flat Ck, Brothers Valley; Common Petrel Pk, Waterfall Lake, Major Lake, Lusitania–Waterfall Bay; sparse elsewhere on coast including S coast	Occur on all coastal areas; not so common inland as in 1965–66; population estimated midway between 50 000 and 150 000; see fig. 1	Sobey et al. (1973)
1973	Common on NW coastal slopes			Skira (1979)
1974	Very few in same area as above; noticeable vegetation regrowth in areas formerly grazed		No major changes in distribution since 1970–71 except for Bauer–Isthmus area	Skira (1979)
1974	Sparse, N of Sandy–Bauer Bays; not on feldmark, coastal terrace or North Head	Largest concentration between Square Lake and Pyramid Peak, including Flat Ck valley; also Major Lake & Lusitania–Waterfall coastal terrace; sparse, S of this	Total numbers estimated 50 000; see(1982) fig. 1	Brothers et al.
1974–1979	Severe grazing of NE coastal slopes in 1976 between Sandy Bay and Isthmus	Increase in numbers N of Green Gorge to Sandy Bay, especially on W coast terrace (slower increase at Green Gorge; very little increase S of Major Lake to Hurd Pt	Slow increase in numbers to estim. peak of 150 000 in 1977–78; distribution similar to 1974; myxomatosis introduced November 1978	Copson et al. (1981) Brothers et al. (1982) N. Brothers, unpub. data

* North of Sandy Bay–Bauer Bay
** South of Sandy Bay–Bauer Bay

IMPORTANCE OF MACQUARIE ISLAND FOR UPPER ATMOSPHERE PHYSICS

by K.D. Cole

(with three tables and three text-figures)

COLE K.D., 1988 (viii): Importance of Macquarie Island for upper atmosphere physics. *Pap. Proc. R. Soc. Tasm.*, 122(1): 267–272. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Physics, La Trobe University, Bundoora, Victoria, Australia 3083.

Macquarie Island, because of its position, has unique advantages as an auroral zone station for studies of upper atmosphere physics, since the effects of solar electromagnetic and of particle radiation are most easily separated at such a station. It is also well placed for the study of fundamental processes in ionospheric and space physics. Understanding of the ionosphere and upper atmosphere at auroral latitudes is essential for understanding of these regions over Australia.

Key Words: Macquarie Island, upper atmosphere physics, ionosphere, auroral zone.

INTRODUCTION

There are three major features which make Macquarie Island important as a site for observatories for upper atmosphere and space research. These are (1) its proximity to the southern auroral zone, (2) its unique geophysical attributes, and (3) its position with respect to Australia. These features will be discussed in turn.

AN AURORAL ZONE STATION

Macquarie Island's "invariant" magnetic latitude (64°S) is slightly equatorwards of the statistically averaged auroral zone. Frequently the auroral oval (the instantaneous belt of visible auroras) is over or equatorwards of the island. This means that many of the phenomena which follow the interaction of the solar wind with the geomagnetic field in space, can be observed there. These include the aurora, the auroral electrojet and the associated ionospheric and thermospheric disturbances, together with certain classes of geomagnetic pulsation.

The two principal sources of energy for the thermosphere (see fig. 1) are the extreme ultraviolet radiation of the sun and the solar wind. The former delivers energy in greatest amount at the subsolar point, and to other sunlit places in lesser amounts determined by the solar–zenith angle (e.g., Chapman & Bartels 1951). The solar wind, on the other hand, delivers its energy to the upper atmosphere by complicated pathways, not yet completely understood, to a belt about the two

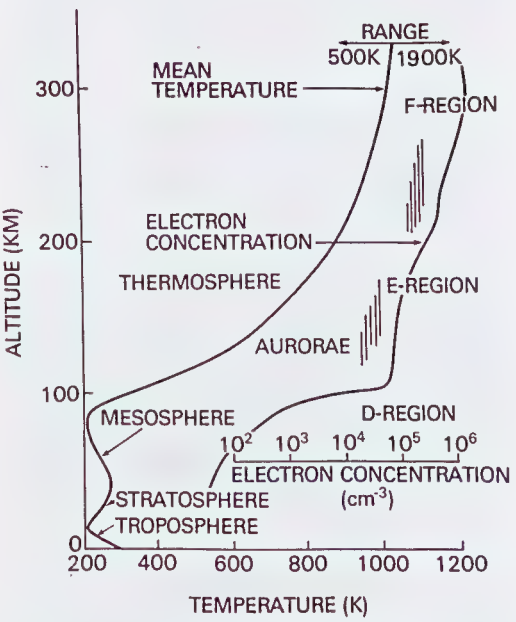


FIG. 1 — The major regions of the earth's atmosphere.

magnetic poles, the belt being on average about 23° removed from the poles. At any instant the auroral oval forms a ring around each pole, such that the ring is much closer to the pole at midday (in "magnetic" time, i.e. time based on a magnetic pole) than at midnight.

Solar Wind–Geomagnetic Field Interaction

The gross features of the interactions of the solar wind and the geomagnetic field are illustrated in figure 2. The geomagnetic field is folded back on the day side to reveal a cusp there in the outer geomagnetic field and to produce a long tail of the field on the night side. A boundary layer is formed about the geomagnetic equatorial plane, in which solar wind plasma flows through the outer geomagnetic field. Plasma processes in the cusp, the boundary layer and the geomagnetic tail (filled with plasma, called the plasma sheet) couple to the atmosphere via electric currents along geomagnetic field lines to produce (1) fluxes of energetic electrons and ions producing auroras in the auroral oval; (2) strong electric fields orthogonal to the geomagnetic field in the thermosphere causing the auroral electrojet (an intense horizontal electric current in the ionosphere; (3) pulsations of the geomagnetic field; and (4) fluxes of atmospheric ions to the magnetosphere (that part of space above the ionosphere occupied by the geomagnetic field).

In addition to these phenomena, an intense electric current around the earth (known as the ring current) is often produced in space, on magnetic field lines very much equatorward of Macquarie Island. This ring current has associated with it a special aurora (Cole 1965, Kozyra *et al.* 1987) known as the stable auroral red arc (SAR arc).

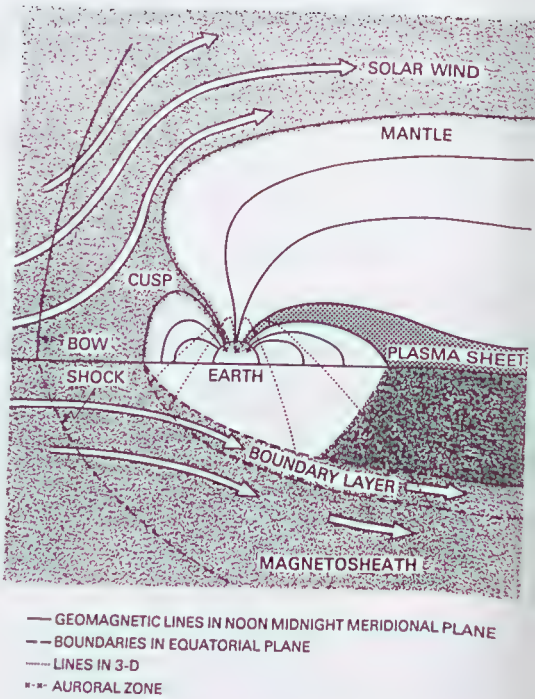


FIG. 2 — Schematic representation of the regions of the geomagnetic field deformed by the solar wind.

Ionosphere–Thermosphere Responses

For a significant fraction of the time, the globally averaged input of energy into the ionosphere–thermosphere system by solar wind interaction with the geomagnetic field exceeds that due to solar extreme ultraviolet radiation. Locally, in the instantaneous auroral oval, this is always the case. (Undoubtedly this is the case at night!) The important consequence is that the global distributions of temperature, air pressure, density and winds at thermospheric altitudes are crucially dependent upon the variable input of solar wind energy (Cole 1966, Fuller-Rowell & Rees 1981). The orbits of satellites in the thermosphere are affected. Sometimes the disturbance winds of the thermosphere are supersonic.

Changes in composition of the thermosphere are brought about by auroral ionisation, upwelling due to joule heating by ionospheric electric currents, and transport away from auroral region by disturbance wind systems. Despite the very bad conditions of cloud cover at Macquarie Island, a great number of fundamental auroral ionospheric and thermospheric processes are amenable to observation from there. Radio and low-frequency electromagnetic techniques, which are unaffected by weather, can be used to study the auroral ionosphere, as indicated in table 1.

Optical methods can be used effectively with clear skies to study auroral and upper atmosphere processes, as indicated in table 2.

In addition, acoustical methods could be used to study the emission of infrasound in the auroral ionosphere.

Mesosphere–Stratosphere

Of great current interest is the extent to which the effects of solar and geomagnetic disturbance penetrate below the thermosphere into the mesosphere and stratosphere (Cole 1977) and, indeed, even into the troposphere. The effects to be studied are of several kinds. Firstly, there are the chemical effects due to relativistic electrons and solar cosmic rays which, by the production of ionisation and consequently nitric oxide, lead to the catalytic destruction of ozone. Next, there is the

TABLE 1

Techniques (Weather-Independent) for Study of Auroral Ionosphere

Technique/ Instrument	Phenomena
Ionosondes	Ionospheric characteristics
Radar	Ionospheric density drift and temperatures of electrons and ions
Faraday rotation	Total electron content of ionosphere
Magnetometers	Auroral electrojet/ geomagnetic pulsations
VLF recorders	Wave particle interactions in the magnetosphere
Scintillation	Ionospheric fine structure

TABLE 2

Techniques (Clear-Sky) for Study of Auroral and Upper Atmosphere Processes

Technique/ Instrument	Phenomena
All sky camera	Aurora
Photometers	Auroral emissions/ozone absorption
Fabry-Perot interferometers	Temperatures and bulk velocity of emitting species of molecule or ion
	Exchange of particles between ionosphere and magnetosphere

chemical effect of the aurora itself, which produces more nitric oxide than is thought to be released into the atmosphere from the surface of the earth (Cole 1984). The long lifetime of nitric oxide may allow it to diffuse downwards sufficiently far to catalytically destroy ozone. Perturbations to ozone may lead to changes in the thermodynamics of the upper atmosphere. The extent to which turbulent diffusion in the mesosphere and upper atmosphere is changed during auroral and magnetic storms is a topical question.

UNIQUE FEATURES OF MACQUARIE ISLAND

Geographic versus Geomagnetic Latitude

The large asymmetry of the geomagnetic field with respect to the geographic poles gives Macquarie Island special interest. The antarctic geomagnetic pole is tilted some 15° towards Australia from the South Pole. This has the important consequence that Macquarie Island is at a high magnetic latitude but at a relatively low geographic latitude, in contrast to the Falkland Islands, in the American longitude, which are at a very low magnetic latitude and a similar geographic latitude. By comparing and contrasting the behaviour of the ionosphere in these two places it will be possible to untangle those parts of ionospheric variation which are due to solar zenith angle effects from those which are caused by the solar wind and solar cosmic rays. Because the arctic magnetic pole is relatively close to the north geographic pole, the resolution of phenomena in the northern hemisphere is not so easily effected.

Conjugacy with Kotzebue, Alaska

Auroral phenomena occur conjugately, i.e. in opposite hemispheres on the same magnetic field lines. The differences of the conjugate auroras may be related then to (1) differences of the geomagnetic field at auroral heights in the two hemispheres; and (2) differences in the density and composition of the thermosphere in the two hemispheres. There are few places in the world where conjugate points both exist on solid earth (usually one is on the ocean). Macquarie Island offers good opportunities for conjugate point studies of upper atmosphere phenomena with Kotzebue, Alaska (see fig. 3), with which it is approximately conjugate.

An "Island" Station

Macquarie Island is a block about 33 km long and 2 km wide with its length running north–south. There will be numerous occasions when the auroral electrojet is overhead or nearby, inducing strong electric currents in the ocean. These currents will be deflected by the island and will produce characteristic variations determined by the relative orientation of the island and the auroral electrojet. This is a fortuitous circumstance exploitable for geophysical studies of earth induction.

Hemispherical Differences in the Lower Atmosphere

Because of the orographic differences of the northern and southern hemispheres, and the relative symmetry of the southern ice-cap compared with the northern polar region, the general circulation of the lower atmosphere exhibits greater symmetry about the south pole than about the north pole. Macquarie Island is well placed for use in observing stratospheric and mesospheric dynamic phenomena related to the general circulation, and for inter-hemispheric comparisons of similar data.

International Programmes

The unique features of Macquarie Island make it a valuable observatory site for international upper atmosphere physics programmes which are conducted under the auspices of the Scientific Committee on Solar-Terrestrial Physics in the International Council of Scientific Unions (see table 3).

SPECIAL ADVANTAGES TO AUSTRALIA

Eastern Australia

The variation of the ionosphere and thermosphere over Australia is controlled to a large extent by auroral zone upper atmosphere processes because the antarctic magnetic pole is displaced a great distance towards Australia. Understanding of the ionosphere over Australia is dependent upon understanding of the auroral ionosphere and processes therein. This gives Macquarie Island a special importance because it is the nearest auroral zone station to eastern Australia. Simultaneous studies of the upper atmosphere at Macquarie Island and Melbourne are being performed at La Trobe University and the Antarctic Division in collaboration.

TABLE 3

Upper Atmosphere Physics Programmes

Programme	Time
Middle Atmosphere Cooperation (MAC)	current
World Ionosphere–Thermosphere Study (WITS)	1987–90
Solar–Terrestrial Energy Programme (STEP)	1990–95
International Geopshere–Biosphere Programme (IGBP)	1990's

Auroral Zone–Equatorial Connection

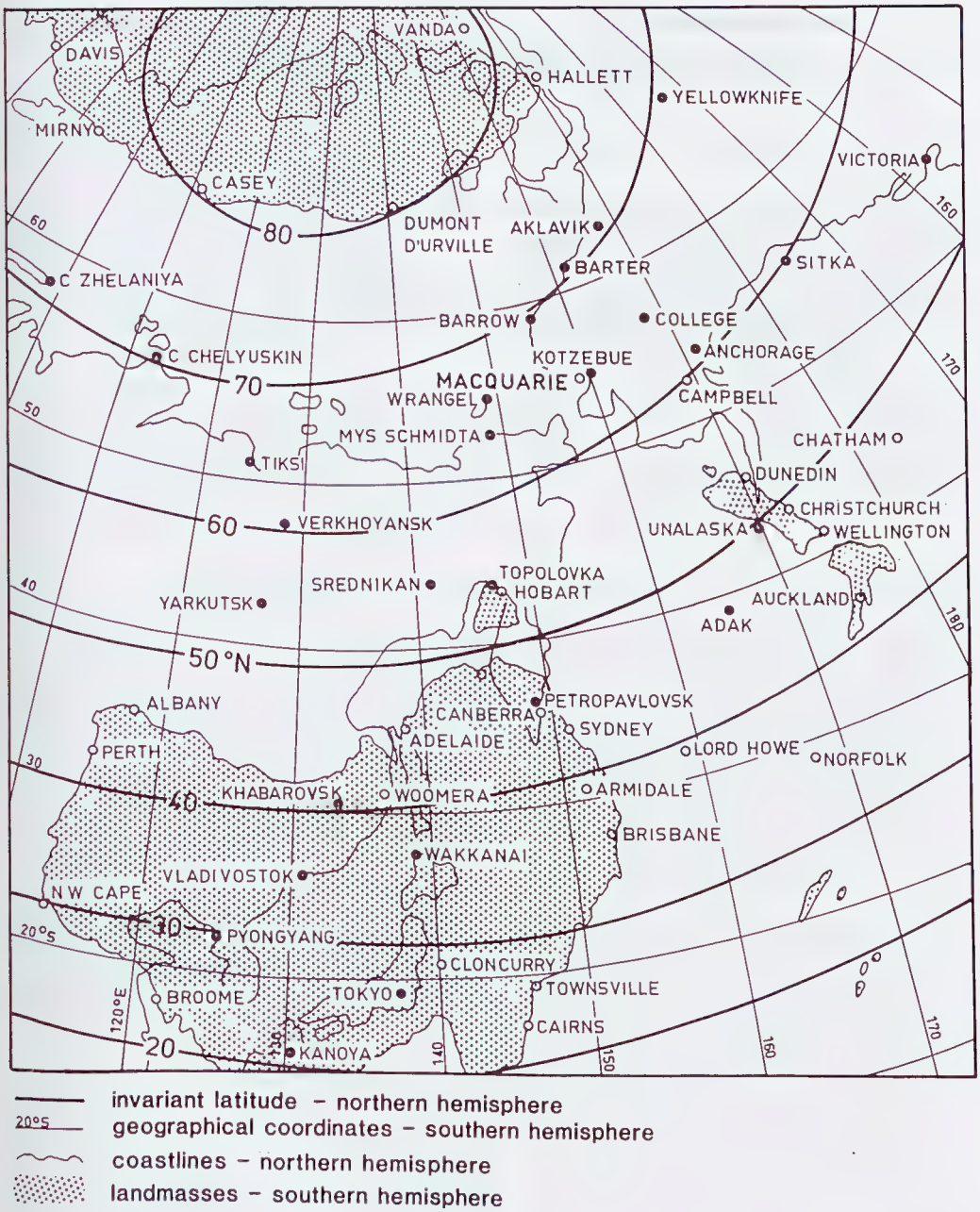
Electric field, winds and waves emanate from the auroral oval and percolate at different characteristic speeds all over the earth in the ionosphere–thermosphere system. Thus, a component of disturbance in the equatorial ionosphere is due to auroral zone processes. Macquarie Island provides us with our closest auroral zone observatory to provide data on these connections.

Jindalee Over-the-Horizon (OTH) Radar

Australia's "Jindalee" OTH radar system, though looking towards the north, will have its signals interfered with from time to time by ionospheric disturbance, related not only to solar activity in electromagnetic emissions but also to solar wind interaction with the geomagnetic field and consequent processes in the auroral zone, as mentioned above. Again, Macquarie Island could play a significant role in interpretation of some records of the Jindalee instruments. Conversely, the Jindalee instruments have potential for use in contributing to fundamental research of ionospheric processes.

CONCLUSION

It is concluded that Macquarie Island has numerous advantages for an auroral zone station not shared with any other, being close to the southern auroral zone, having magnetic latitude different from its geographic latitude, and being the auroral zone station nearest to Australia. Separation of the effects of solar electromagnetic radiation and particle radiation upon the upper atmosphere, a fundamental problem in understanding the energy and dynamics of the thermosphere, is most easily achieved at such a station. This is important, both for local upper atmosphere studies and for contributions to upper atmosphere studies over Australia and further north. The relative ease of access to Macquarie Island by sea and by air-drop is a significant bonus.



invariant latitude – northern hemisphere

20°S geographical coordinates – southern hemisphere

coastlines – northern hemisphere

landmasses – southern hemisphere

FIG. 3 — Conjugate magnetic map, showing major places and their conjugates.

REFERENCES

CHAPMAN, S. & BARTELS, J., 1951: *GEOMAGNETISM*. Oxford University Press, London.

COLE, K.D., 1965: Stable auroral red arcs, sinks for energy of D_{st} main phase. *J. Geophys. Res.*, 70: 1689–1706.

COLE, K.D., 1966: Magnetic storms and associated phenomena. *Space Sci. Rev.*, 5: 699–700.

COLE K.D., 1977: Energy balance of the atmosphere under the influence of a disturbed sun and magnetospheric processes. *In* Grandal, B. & Holtet, J.A. (Eds): *DYNAMICAL AND CHEMICAL COUPLING*. D. Reidel Publ. Co., Dordrecht, Holland: 203–216.

COLE, K.D., 1984: Possible effects of solar variability on the middle atmosphere. *J. Atmos. Terr. Phys.*, 46: 721–725.

FULLER-ROWELL, T.J. & REES, D., 1981: A three-dimensional time-dependent simulation of the global dynamical response of the thermosphere to a geomagnetic substorm. *J. Atmos. Terr. Phys.*, 43: 701.

KOZYRA, J.E., SHELLEY, E.G., COMFORT, R.H., BRACE, L.H., CRAVENS, T.E. & NAGY, A.F., 1987: The role of ring current O^+ in the formation of stable auroral red arcs. *J. Geophys. Res.*, 92: 7487–7502.

(accepted 1 October 1987)

A COMPARISON OF MAP SYSTEMS WITH MACQUARIE ISLAND MONTHLY MEDIAN IONOSPHERIC DATA

by Carl Esposito

(with three tables and five text-figures)

ESPOSITO, C., 1988 (viii): A comparison of map systems with Macquarie Island monthly median ionospheric data. *Pap. Proc. R. Soc. Tasm.*, 122(1): 273–281. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. IPS Radio and Space Services, P.O. Box 702, Darlinghurst, New South Wales, Australia 2010.

This work analyses the performance of five map systems of foF_2 (critical frequency) at Macquarie Island, in the Southern Ocean. Both gridpoint-based and coefficient-based maps were included in this study. Macquarie Island was chosen as the site for a case study of the performance of the map systems because of its proximity to Australia, combined with its isolation and high magnetic latitude. A statistical inference method was used to give a measure of how well each map estimated monthly median values of foF_2. It was concluded that more samples are required to adequately define the variability of foF_2 with solar activity at Macquarie Island.

Key Words: map systems, foF_2, ionospheric prediction, Macquarie Island.

INTRODUCTION

Macquarie Island is the site of a continuing programme of high latitude upper atmospheric research. It is important because it is the only station now operating between Australia and Antarctica. Since it lies at about the halfway point, knowledge of the ionosphere in the vicinity of Macquarie Island is important for HF communications in the region between Australia and Antarctica. It is also interesting because of the presence of the auroral oval, which passes over the island.

In such an important natural laboratory, it is essential to have as complete a knowledge as possible of those parameters of the state of the ionosphere that can be easily measured. The most important of these parameters is foF_2 (the critical frequency of the ionospheric F-region at vertical incidence).

In order to assess the various map systems describing foF_2, the predictions derived using the maps were compared with monthly median data at Macquarie Island. This study incorporates both the gridpoint-based map systems (used by Ionospheric Prediction Service — IPS) and the coefficient-based map systems (used by International Reference Ionosphere — IRI — and Ionospheric Communications Analysis and Predictions Programme — IONCAP).

EVALUATION OF MAP SYSTEMS

Global maps of foF_2 were developed to represent the spatial and temporal variability of foF_2 for each month of the year, at an arbitrary level of ionospheric activity. Their usefulness lies in their ability to estimate values of foF_2 where no data exist. This predictive capacity is assessed for one region of importance to Australia. One application is in the calculation of the total electron content from Faraday rotation measurements, which requires knowledge of foF_2 in the region north of Macquarie Island; this can be obtained from the maps.

foF_2 data exist for Macquarie Island sporadically, during the period from June 1950 to November 1958 and from November 1983 to the present; some of these data have not been used in the derivation of any of the maps. For instance, data from 1950–53 were not used in either the International Radio Consultative Committee (CCIR) maps or the Rush/Institute for Telecommunications Science (ITS) maps, and data from 1984–85 were not used in any of the maps. The map estimates can be compared with these data to give a measure of the accuracy of their predictions, although data from the 1950's is generally not as reliable as data from the 1980's.

The performance of the map systems at Macquarie Island was assessed for the current sunspot cycle by comparing the map predictions with 1984 monthly median data and also with 1951

TABLE 1
Activity Indices

Month	R_{12}		T index	
	1951	1984	1951	1984
January	71.7	60.0	65.3	61.2
February	69.5	56.0	59.9	72.0
March	69.8	53.0	53.5	80.0
April	70.7	50.0	62.5	71.6
May	70.2	48.0	60.3	55.3
June	69.8	47.0	68.3	58.2
July	68.6	44.0	69.3	42.5
August	66.3	40.0	56.2	32.1
September	63.3	34.0	58.1	32.4
October	59.2	29.0	61.8	13.3
November	53.0	25.0	61.5	16.9
December	46.8	22.0	60.8	19.5

data, since in both years there were medium levels of solar activity. This allowed comparison between sunspot cycles. Both 1951 and 1984 were in the decay part of the sunspot cycle, sunspot maxima having occurred during 1947 and during 1980. Table 1 lists the twelve-month smoothed Zurich sunspot numbers, R_{12}, for 1951 and 1984.

Table 2 summarises the map systems investigated. The coefficient-based map systems use the Jones & Gallet (1965) method. A series of functions analogous to surface spherical harmonics was used to represent the global structure of foF_2 for a particular month and level of solar activity, represented as two sets of numerical coefficients for a nominal twelve-month smoothed sunspot number of 0 and 100 for each month of the year. When an estimate of foF_2 was required at a different level of solar activity, it was extrapolated from these maps. The extrapolation assumes a linear relationship between foF_2 and R_{12}.

The IPS maps use an index of ionospheric activity — the T index — more highly correlated with foF_2 than is R_{12}. The T indices for 1951 and 1984 are given in table 1. All the map systems discussed employ a co-ordinate system based on a modified magnetic dip and geomagnetic longitude.

IPS Maps

Two IPS gridpoint map systems were considered in this study. They were designated as the old IPS maps and the new IPS maps. The most recent of the old IPS maps were digitised in 1972 from existing hand-drawn maps, and are still used by IPS Radio and Space Services to make predictions.

Fox & McNamara (1986) described the development of the new IPS map system. The new IPS map values are stored as gridpoint data derived from the sets of coefficients rather than as

TABLE 2
Map Systems

Maps	Data Used	Filling of regions with no data	Map representation
old IPS	All station data available to 1972	Hand drawn and subsequently digitised	Gridpoint maps
new IPS	All station data available to 1982	Rush/ITS model values at mid-latitudes and modified values from old IPS map elsewhere	Gridpoint maps
CCIR	1954–58, 1964	Extrapolates land-based observations along lines of constant modified magnetic dip	Numerical coefficients
Rush/ITS	July 1975–June 1976, July 1978-June 1979	Theoretical values at mid–latitudes	Numerical coefficients
URSI	As for new IPS	As for new IPS	Coefficients (derived from new IPS gridpoint maps)

the coefficients themselves. Although this takes up more space on a computer, it allows faster predictions to be made. It also permits small-scale revisions of the maps in accordance with new data as it becomes available. Smoothing of diurnal curves was carried out for each gridpoint in the old IPS maps. The derivation of each of the new IPS hourly maps was largely independent; there is no guarantee of smooth diurnal behaviour.

The accuracy of predictions of foF_2 at different levels of ionospheric activity depends on how well regression between activity index and foF_2 is defined. To derive a regression applicable to a number of sunspot cycles, samples must be acquired from many different cycles. In recognition of this, the new IPS maps used all the station data available at IPS to 1982. For instance, records at Hobart began in December 1945; this represents nearly four complete sunspot cycles.

Coefficient-based Maps

The CCIR maps (CCIR 1983) used a full sunspot cycle (1954–58) to derive the sets of numerical coefficients, with 1964 contributing supplemental data for sunspot minimum. The Rush/ITS maps (Rush *et al.* 1984) used only two years of data. July 1975–June 1976 was used as representative of sunspot minimum, while July 1978–June 1979 was used as representative of sunspot maximum. The problem with using data from just one cycle in deriving the coefficients is that it assumes that the cycle used is in some way typical of all other cycles. Therefore, difficulties may arise when attempting to estimate values of foF_2 in different cycles.

The International Union of Radio Science (URSI) coefficients were derived from a remapping of the new IPS maps in the standard CCIR format. They were tentatively adopted by URSI at the Ionospheric Modeling Workshop held at Boulder, USA, in August 1986, and were due to be ratified at the URSI General Assembly in Tel Aviv, Israel, August 1987. They were derived from a filled database (the new IPS maps), so no additional data are required.

The technique used by Jones & Gallet (1965) is liable to give non-physical results in data-sparse areas. In an attempt to overcome this shortfall, the CCIR maps interpolate between land-based observations along lines of constant modified magnetic dip. Rush *et al.* (1984) used theoretical values of foF_2, derived from the time-dependent continuity equation for ions (and electrons) at mid-latitudes. These theoretical values were also used in the new IPS maps to fill in ocean regions at mid-latitudes. Values derived from the old IPS maps were employed at high and low latitude.

COMPARISONS OF MAP PREDICTIONS WITH OBSERVATIONS

Figure 1 shows the distribution of foF_2 values for each hour for March 1984. All the hourly values of foF_2 measured at a particular time of the day during the month were used to calculate the percentiles displayed. As shown in the key, the cross in the middle of the rectangle represents the median. The top and bottom of the rectangle are the upper and lower quartiles, and the limits of the lines outside the rectangle are the upper and lower deciles. Thus, one symbol represents the distribution of foF_2 values measured at a particular time over a whole month. The width of the rectangle is proportional to the number of data values in the sample. This gives an estimate of the reliability of the statistics plotted.

The median values thus derived were compared with predictions from each of the map systems. Predictions were made, using the known value of R_{12} or T index (table 1), for the month in question.

A Statistical Inference Method

Although a subjective idea of the performance of the maps can be obtained from this plot, it would be of benefit to have a more exact method for measuring their performance. The root mean squared error of the map estimates of the monthly median values gives one such measure. It takes no account of the variability of the sample distribution. Statistical inference facilitates a decision on whether a map estimate could be consistent with the sample distribution. Because it makes an hour-by-hour comparison, it also gives information on how well the shape of the estimated diurnal curves matched the data. It gives an answer to the question: could the map estimate at a particular hour be a true estimate of the unknown population median?

This question can be cast as a hypothesis for a statistical inference problem. From the sample statistics, an estimate of an upper and lower bound on the unknown population median can be found. If the hypothesised value (i.e., the map estimate) lies outside this range, then the hypothesis is rejected. In this way, a verifiable statement on whether or not to reject the map estimate can be made.

Comparisons made for typical months throughout 1984 and for March 1951 at Macquarie Island are presented in figures 2–5. The performance of each map for a particular month was quantified using a statistical inference method. For each hour of the day, the following procedure from Switzer (1983) was applied:

(1) All the measured foF_2 values for the chosen time of day during a particular month were used to calculate the sample median and an associated confidence interval. The underlying population median has a probability, $1-\alpha$, of lying inside this confidence interval.

(2) For the estimation of a general population quantile, the confidence interval estimate may be expressed as

$$\hat{Q}(p-g_\alpha) \leq Q(p) \leq \hat{Q}(p+g_\alpha),$$

where $Q(p)$ is the unknown population quantile and $\hat{Q}(p)$ is the quantile function of the sample data.

(3) In the case of median estimation, $p = 0.5$. For a coverage probability of 90%, the required value of α is 0.1. If $\alpha = 0.1$, $g_\alpha = 0.82/N^{1/2}$. In general, a smaller sample size means a larger confidence interval.

A hypothesised value for the median of foF_2 was calculated using each of the maps in question. If the estimate lay outside the confidence interval, the hypothesis was said to have failed at the 10% significance level.

The results of the inference for each hour of the day were combined as a single score, giving a measure of the performance of the maps for the month in question. This inference score represented the number of times that a model failed to produce an estimate for foF_2 that lay inside the confidence interval for the median. The scores ranged from 0 to 24. Twenty-four was the worst case, where every median confidence interval was missed.

TABLE 3

Results of Median Inference, Macquarie Island

Month	Inference Score				
	URSI	Rush/ITS	new IPS	CCIR	old IPS
(a) 1984					
January	14+	17+	18+	17+	12+
February	5–	6–	6+	5–	4+
March	7–	7–	5+	11–	6–
April	13–	14–	6+	15–	7–
May	11+	11–	14+	9+	11+
June	7+	10–	9+	12+	17+
July	7+	18+	7–	9–	13–
August	13+	15+	9+	12+	9+
September	16+	17+	15+	15+	14+
October	19+	17+	18+	17+	9+
November	20+	18+	18+	19+	13+
December	23+	22+	19+	24+	17+
(b) 1951					
January	18+	17+	9+	12+	9+
February	11+	9+	5+	9+	7+
March	15+	15+	13+	15+	7–
April	6+	4–	8–	3–	7–
May	11+	7+	10+	6+	7+
June	11+	13–	11+	7+	5+
July	8–	13–	12–	14–	16–
August	14+	16+	11+	10+	9+
September	19+	21+	13+	15+	3+
October	11+	18+	11+	12+	1+
November	7+	8+	10+	3+	3–
December	5+	11+	6+	5+	6–

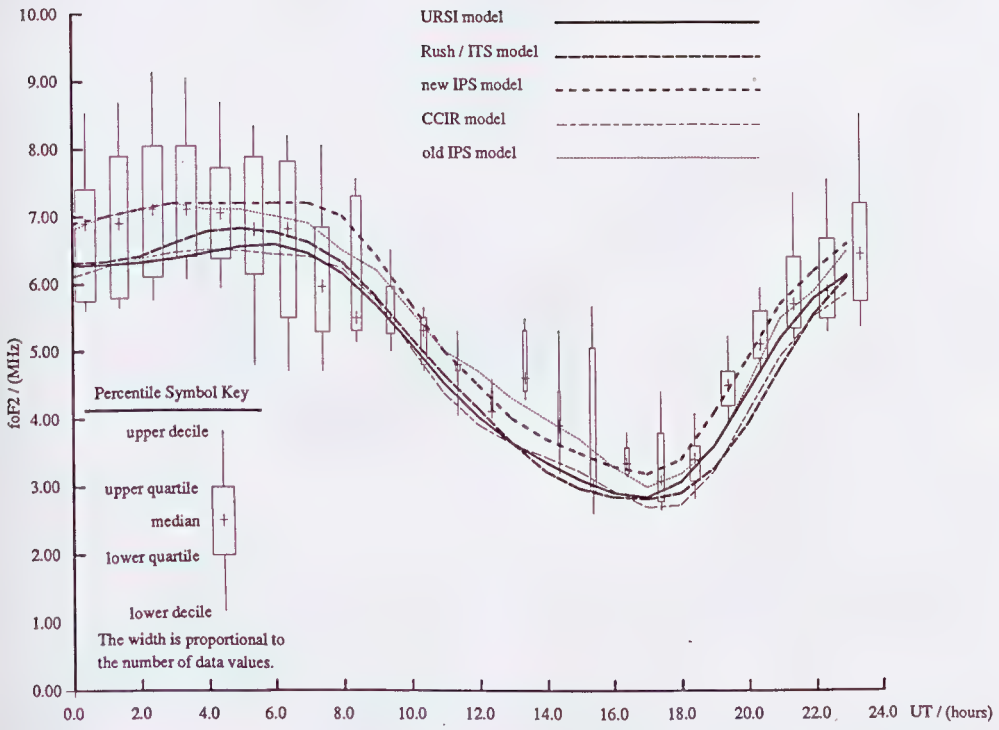


FIG. 1 — Comparison of measured foF_2 *distribution with models, March 1984.*

RESULTS AND DISCUSSION

1984 Comparisons

Statistical Inference Scores

The results of the analysis for 1984 at Macquarie Island are shown in table 3(a). The presence of the symbols + or – indicates whether the estimates not accepted were above or below the 90% confidence interval. The absence of a sign indicates that the estimates were distributed equally above and below the confidence interval.

The old IPS fared best of all the maps for the whole year. But only in February and May were less than 50% of the estimations outside the confidence interval. All the maps scored worse during spring and most of summer than the rest of the year. Most of the rejected estimates fell above the upper bound on the median.

Graphical Comparisons

Figures 2–4 are the graphical representation of the statistical inference results for typical months in 1984. For March 1984 (fig. 2), the CCIR map system performed the worst, lying outside the confidence interval 50% of the time. The other map systems performed better, but still far short of the required accuracy. The night-time confidence intervals show a large variability in the sample distribution. This could be due to a combination of day-to-day variability in the level of ionospheric activity during the month and the small sample size.

In June 1984 (fig. 3), the old IPS map system performed the worst. It overestimated the daytime peak, but followed the night-time values quite well.

The differences between the new IPS map values and those derived from the URSI maps exist because different functions were used. Also, the

FIG. 2 — Comparison of median 90% confidence intervals with models, March 1984.

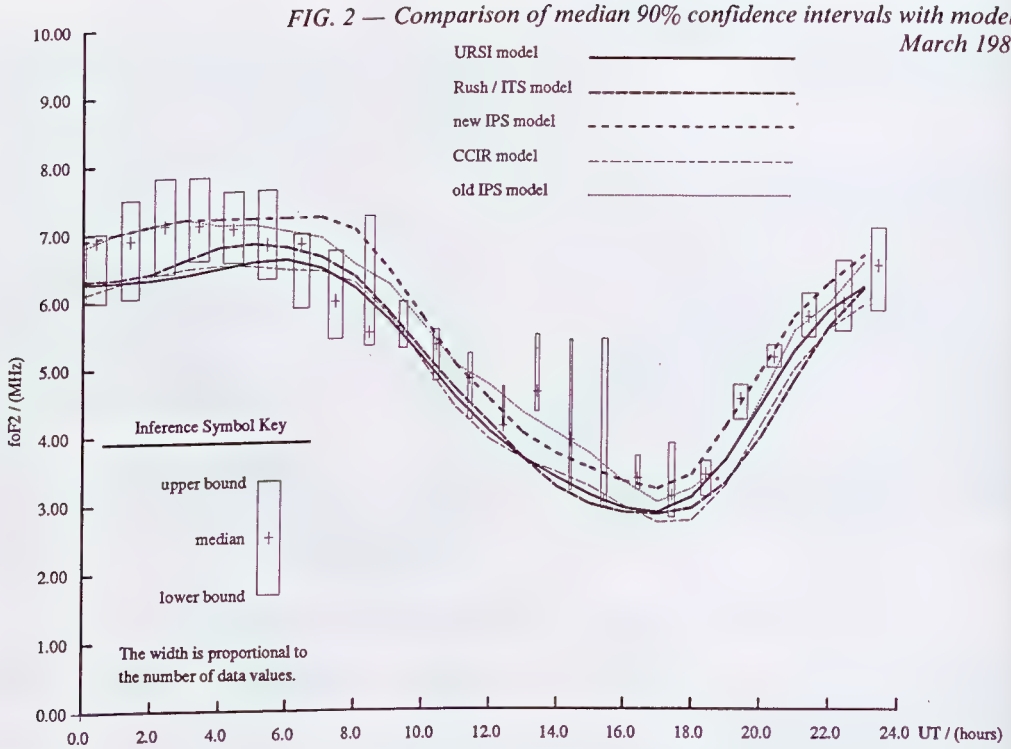
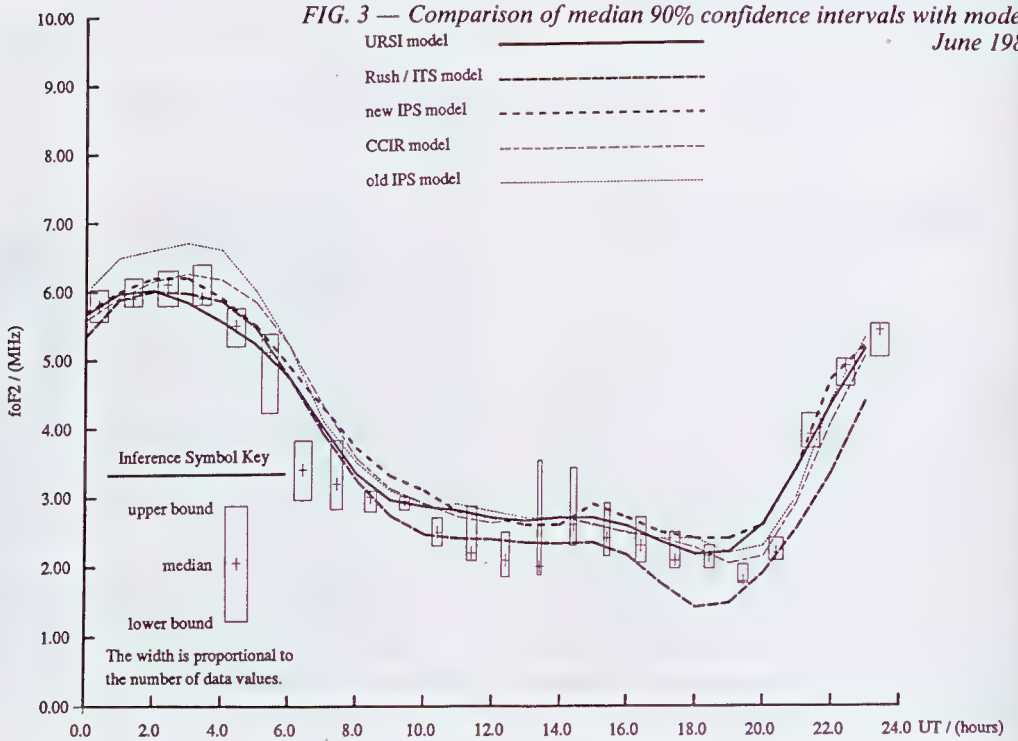


FIG. 3 — Comparison of median 90% confidence intervals with models, June 1984.



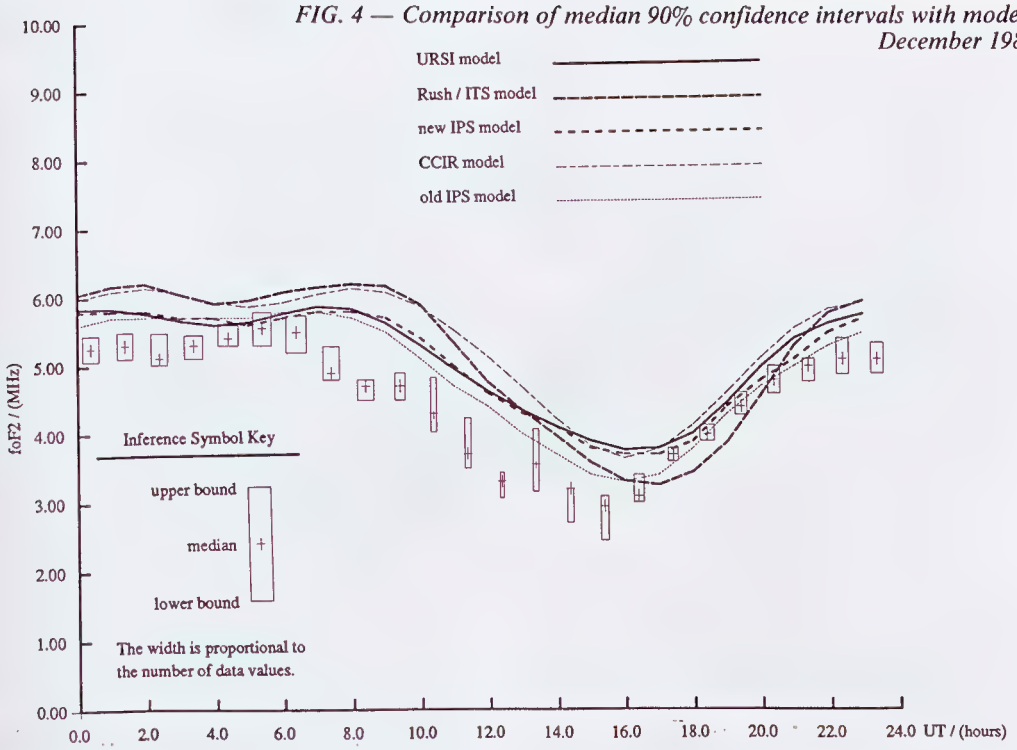


FIG. 4 — Comparison of median 90% confidence intervals with models, December 1984.

URSI maps used R_{12} while the new IPS maps are based on the T index.

While for March to July there are a total of 22 years of samples, there are only between seven and nine years for the rest of the year. So between March and July, only two sunspot cycles have been sampled so far, and less than one for the other months. Inadequate sampling means that the regression between foF_2 and activity index — R_{12} or T index — is not completely defined. This probably explains why the new and old IPS maps and URSI maps fared worse from September to December (see table 3(a)). The graphical presentation for December is shown in figure 4. All of the maps tend to overestimate the median ranges. This is undesirable because communication may not be possible via the F_2 region using predictions based on the map system's median estimate.

1951 Comparisons

Statistical Inference Scores

The results for 1951 are presented in table 3(b). 1951 data were not used in the CCIR maps or the Rush/ITS maps. The results are markedly better for all maps, with a large improvement over 1984 results toward the end of the year. The predictions made using the old IPS maps lie outside the median confidence interval less than 10% of the time for September to November. This condition is met by the CCIR maps for April and November.

Graphical Comparisons

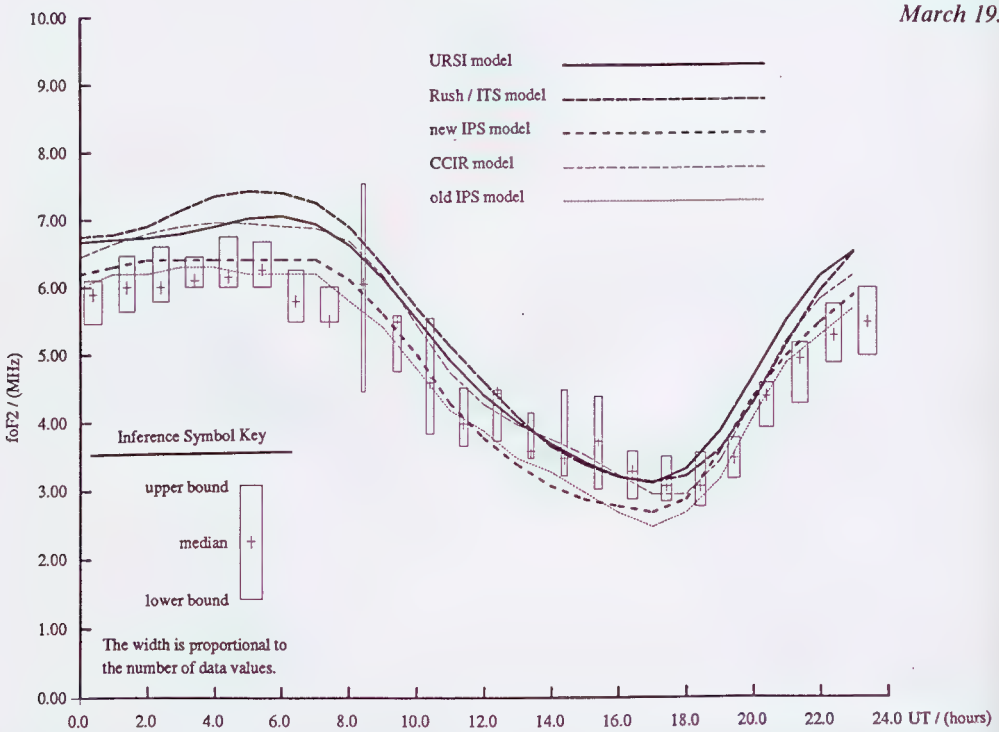
A comparison of the results for March 1951 is presented in figure 5. The IPS maps matched the midday peak, but underestimated the night-time values. The opposite occurs for the other map systems. They matched the night-time values, but overestimated the midday peak.

Discussion

The graphical comparisons show inadequacies in the shape of all the map systems' diurnal curves; especially for March 1951 (fig. 5). December 1984 (fig. 4) also displays an incorrect diurnal variation. A proportional error was evident as well, there being a consistent overestimate of the medians.

All the maps relied on extrapolation using the established regression between the chosen

FIG. 5 — Comparison of median 90% confidence intervals with models, March 1951.



activity index and foF_2. Because this regression is generally good, for R_{12} or T index, it was expected that they would compare favourably with the median data.

None of the maps used data from 1984 at Macquarie Island. Therefore, all of the map systems used the established regression between the activity index and foF_2, in order to make an estimate of foF_2 for each month and, except for the Rush/ITS maps, they all used data from Macquarie Island. The nearest station used by the Rush/ITS maps was Campbell Island. It is close geographically, but behaves quite differently because of the reduced likelihood of the occurrence of aurorae. The Rush/ITS maps therefore used a spatial extrapolation as well.

Better results during the 1950's, compared with the 1980's, implied that the established regression was not applicable during the present sunspot cycle. It is expected that the situation will improve as more samples from the current sunspot cycle are collected and included in the regression. The results emphasise the danger of limiting the map system database to one sunspot cycle, as for the CCIR maps and Rush/ITS maps.

Disturbed conditions in the ionosphere will produce anomalous values of foF_2. They will manifest themselves as outliers in the sample distribution, and consequently will not affect the estimation of the median significantly — the median is a robust estimator.

CONCLUSIONS

The consistency of map system estimates of foF_2 with monthly median values has been determined at Macquarie Island for 1984 and 1951. To be useful in practice, the map estimates should be consistent with the data more than approximately 10% of the time. This condition is met in only a few isolated cases for the CCIR and the old IPS map systems, but not at all for the other map systems. This demonstrates that, at least for one island station, the currently used map systems are not adequate.

The accuracy of the maps depends on how well the analytic functions chosen characterise the natural spatial variability of foF_2. Development of more appropriate functions for representing geophysical spatial data, is a field of active research in

applied mathematics. But, to date, no suitable solutions have been found.

Improvement of the currently used map systems relies on the use of physical knowledge to complement the analytic representation. This sets constraints on the values the functions may take, and complements the measured values in data-sparse areas. The only attempt to introduce a physical model into the empirical maps was put forward by Rush *et al.* (1984). But, as has been shown, this map system performs worse at Macquarie Island than the CCIR map system which it attempts to improve on. The global picture (results not included in this study) is consistent with the findings at Macquarie Island.

It was found that the maps estimated poorly in the 1980's compared with the 1950's at Macquarie Island. The new IPS maps and old IPS maps fared worse in the 1980's because of a lack of samples in the current sunspot cycle. The CCIR and Rush/ITS maps also fared worse, possibly because the cycle on which they are based is not typical of the current cycle. The lack of data can be remedied by continued monitoring of foF_2, and inclusion of these data in future map revisions. As a global initiative, stations such as Macquarie Island, lying in data-sparse regions, should be maintained and new stations opened.

IPS is currently developing the digital 5A Ionosonde for deployment at Australian upper atmospheric research stations, including Macquarie Island. This should allow consistent high quality data to continue to be collected in the future. More median values will become available, giving rise to more reliable maps in the long term. It will also be possible to use hourly data, as it is acquired, to update the maps so that current conditions can be taken into account.

The development of a map of foF_2, that allows estimates to be made with confidence in data-sparse areas, would be of much value to researchers at Macquarie Island. All the map systems investigated produced estimates inconsistent with the sample distributions for much of the time. The currently used map systems need to be improved, or new map systems need to be developed, in order to increase the reliability of predictions for the Macquarie Island region.

The solution lies in the acquisition of more data, and in research to find more suitable functions for representing the spatial and temporal variability of foF_2 than those currently in use. More appropriate physical models need to be developed to complement sparsely sampled areas.

REFERENCES

CCIR, 1983: CCIR atlas of ionospheric characteristics. *CCIR Report* 340-4. Geneva: 33–38.

FOX, M.W. & McNAMARA, L.F., 1986: Improved empirical world maps of foF_2: 1. The method. *IPS Series R Report, No. IPS TR-86-03.*

JONES, W.B. & GALLET, R.M., 1965: Representation of diurnal and geographic variations of ionospheric data by numerical methods. *Telecomm. J.*, 32: 18.

RUSH, C.M., PoKEMPNER, M., ANDERSON, D.N., PERRY, J., STEWART, F.G. & REASONER, R.K., 1984: Global maps of foF_2 derived from observations and theoretical values. *NITA Report 84-140*, U.S. Department of Commerce.

SWITZER, P., 1983: Statistical methods for exploration and mining. *Workshop Course 267/83 Notes.* The Australian Mineral Foundation, Sydney, 18–22 April: 29–31.

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MACQUARIE ISLAND AND THE AUSSAT RADIO BEACON EXPERIMENT

by E.A. Essex

(with one text-figure)

ESSEX, E.A., 1988 (viii): Macquarie Island and the AUSSAT radio beacon experiment. *Pap. Proc. R. Soc. Tasm.*, 122(1): 283–287. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Department of Physics, La Trobe University, Bundoora, Victoria, Australia 3083.

The second generation AUSSAT (1992 *et seq.*) satellites provide the Australian upper atmosphere scientific community with the opportunity to re-enter the space age. To this end, a proposal for a radio beacon experiment on AUSSAT has been prepared by IPS Radio and Space Services, Department of Science, in conjunction with La Trobe and Monash Universities. The location of the spacecraft in geosynchronous orbit at longitude 156°–164° E means that, unlike the Australian antarctic mainland bases, the subantarctic station of Macquarie Island is ideally suited as a ground station. This paper outlines possible studies, from Macquarie Island, of the near earth plasma using the AUSSAT beacons.

Key Words: AUSSAT, radio beacon experiments, ionospheric studies, Macquarie Island.

INTRODUCTION

The second generation AUSSAT (1992 *et seq.*) satellites provide the Australian upper atmosphere scientific community with the opportunity to design and implement their own scientific experiments in space. To this end, a proposal for a radio beacon experiment on AUSSAT has been prepared by IPS Radio and Space Services, Department of Science, in conjunction with La Trobe and Monash Universities. The proposed beacon would transmit three phase-coherent frequencies (nominally 137, 411 and 1233 MHz), with modulation to permit Faraday, differential carrier Doppler, and group path measurements to be made at ground stations within sight of the satellite. The location of the spacecraft in geosynchronous orbit at longitude 156°–164° E means that the subantarctic station of Macquarie Island is ideally located for ionospheric studies; the Australian antarctic mainland bases are not suitably located for studies using the AUSSAT beacons unless the longitude position is moved further west. The sections following outline the various techniques using AUSSAT beacons which may be used to study the ionosphere.

THEORY AND EXPERIMENTAL DESIGN

Phase path length variations and the derived Doppler shifts are two ionospheric effects which can be monitored using a radio beacon to obtain information on ionospheric parameters. Depending on the type of modulation used, it is also possible to measure the group path delay due to the presence of the ionosphere. These techniques are outlined below, as well as their application to the AUSSAT beacon.

Phase Path Length and Doppler Shift

Following the method of Garriott *et al.* (1970) and Davies *et al.* (1975), the phase length P, under ray theory, of a wave propagating between satellite transmitter T_x and a receiver R_x on the ground is given by

$$P = \int_{T_x}^{R_x} \mu_p \cos\alpha \, ds \qquad (1)$$

where μ_p is the phase refractive index in the wave normal direction and α is the angle between the ray and the wave normal. Under free space conditions, the value of P is R, along the straight line path. So the phase path reduction ΔP due to the ionosphere is given by

$$\Delta P = R - P \qquad (2)$$

Using the QL approximation for the refractive index, two modes exist at high frequencies. The differential phase shift between the two modes

gives the angular motion Ω, called the Faraday rotation, where

$$\Omega = \frac{\pi}{\lambda}(\Delta P_{ord} - \Delta P_{ext}) \text{ radians} \qquad (3)$$

The Doppler shift at the receiver is given by

$$f_D = -\frac{1}{\lambda}\frac{dR}{dt} + \frac{1}{\lambda}\frac{d\,\Delta p}{dt} \qquad (4)$$

corresponding to the free space and ionospheric Doppler shifts.

Neglecting absorption and assuming refraction effects are small, the QL approximation of phase refractive index may be written as

$$\mu_p = 1 - \tfrac{1}{2}\frac{K_1 N}{f^2} \pm \tfrac{1}{2}\frac{K_1 N}{f^3} f_L \qquad (5)$$

where f_L is the electron gyrofrequency corresponding to the longitudinal component of the geomagnetic field along the ray path, f is the wave frequency, N is the electron density and K_1 is a constant equal to 80.6. The phase reduction and the differential phase shift may be written, to a first approximation, as

$$\Delta P = \Delta P_0 = \frac{K_1}{2f^2}\int N ds \qquad (6)$$

and

$$\Omega \approx \Omega_0 = \frac{\pi K_1}{cf^2}\bar{f}_L \int N ds \qquad (7)$$

where the average bar denotes the weighted mean over the integration along a straight line path to the satellite at an angle Ψ to the geomagnetic field.

Assuming the ionosphere is spherically stratified, (6) and (7) may be written as

$$\Delta P_0 = \frac{K_1}{2f^2}\overline{\sec\theta}\int N dh \qquad (8)$$

$$\Omega_0 = \frac{K_1 \pi e \bar{M}}{mc f^2}\int N dh \qquad (9)$$

where θ is the vertical angle of the path and f_L is written in terms of the magnetic field where $\bar{M} = \overline{B\cos\psi\sec\theta}$. The ionospheric Doppler shift becomes

$$\Delta f_{DO} = \frac{K_1 d}{2cf\,dt}\overline{\sec\theta}\int N dh \qquad (10)$$

It is noted that the first order expression for the phase path defect ΔP_0 does not involve the magnetic field, whereas the expression for the Faraday rotation Ω_0 is weighted by the magnetic field.

Considering now the second order approximation, the phase path refractive index may be written as

$$\mu_p \approx 1 - \frac{K_1 N}{2f^2\left(1 \pm \frac{f_L}{f}\right)} \qquad (11)$$

This leads to the following expression for the phase path length reduction

$$\Delta P \approx \frac{K_1}{2f}\overline{\sec\theta}\int \frac{N}{f \pm f_L} dh \qquad (12)$$

and the expression for the Faraday rotation

$$\Omega \approx \frac{\pi K_1}{c}\overline{\sec\theta}\int \frac{f_L}{f^2 - f_L^2} N dh \qquad (13)$$

It is seen now that both ΔP and Ω are dependent on the magnetic field through f_L. Third order expressions for ΔP and Ω are discussed by Ross (1965) and Tucker *et al.* (1968). It is pointed out that the third order approximations involving the non-linearity in μ_p and the ray refraction may be larger than the second order approximations at a given frequency.

Group Path Delay

The group path delay ΔT, relative to free space, between a satellite transmitter T_x and a ground receiver R_x is given by

$$\Delta T = \frac{1}{c}\int_{R_x}^{T_x} \mu_g\, ds - \frac{1}{c}\int_{R_x}^{T_x} ds \qquad (14)$$

where μ_g is the group refractive index at VHF and above. Using the first order approximation for μ_g l where $\mu_g = 1/\mu_p$, this expression may be written as

$$\Delta T = \frac{K_1}{2cf^2}\int N ds \qquad (15)$$

Hence the dispersive group path delay in the ionosphere, relative to the free space time of arrival, is proportional to the ionospheric electron content and independent of the magnetic field in the first approximation.

The second order approximation, obtained from equations (11) and (14), is

$$\Delta T = \frac{K_1}{2cf}\int \frac{N}{(f \pm f_L)} ds \qquad (16)$$

and is dependent on the magnetic field.

Experimental Design

Depending on the type of modulation used on the AUSSAT beacon, the above equations enable different methods and sensitivities to be used to study the variation in the ionospheric and protonospheric electron content. Considering first the Faraday rotation, we have from (7), for two closely spaced frequencies such as 137 MHz and a 1 MHz amplitude modulation, the differential Faraday rotation

$$\delta\Omega = \frac{-2K_1 \pi e \bar{M} \delta f}{mcf^3} \int Ndh \qquad (17)$$

with an error of $\frac{\delta\Omega}{\Omega} = \frac{-2\delta f}{f}$ (18)

This enables the ionospheric electron content to be measured without an ambiguity in Ω, a problem in the past when only a single frequency has been available (see Lambert & Cohen 1986). For two widely spaced frequencies f_1 and f_2 such as 137 MHz and 411 MHz, we have then for the differential Faraday rotation

$$d\Omega = \Omega_2 - \Omega_1 = \frac{-K_1 \pi e \bar{M}}{mc} \left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right) \int Ndh \qquad (19)$$

from which the ionospheric electron content can be determined without ambiguity.

For the chosen frequencies, equation (17) gives a value of around 6° for an ionospheric electron content of 1 TEC unit (= 10^{16}cm^{-2}) at the location of Macquarie Island, looking at AUSSAT located at 160° E. This should just be resolvable; however, for larger ionospheric electron content values, it would be easily resolvable, as $d\Omega$ increases linearly with the ionospheric electron content. For continuous observations, one calibration point during the daytime should resolve the ambiguity. For two widely separated frequencies, equation (19) gives a value of $d\Omega$ around 290° for 1 TEC unit, measured at Macquarie Island. Use of two widely spaced frequencies for Faraday rotation measurements, especially during night-time when the ionospheric electron content is low, should provide an unambiguous value of the ionospheric electron content.

Turning now to the differential Doppler (or differential carrier phase) measurements, when three coherent frequencies are used, such as the proposed 137, 411 and 1233 MHz, it is possible to determine the total electron content. For three coherent frequencies f_1, f_2, f_3 we obtain three equations, using either equations (8) or (10), of the form

$$\Delta P_1 - \Delta P_2 = \frac{K_1}{2} \overline{\sec\theta} \left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right) \int Ndh \qquad (20)$$

These three equations can be solved to give a value of the total electron content with no baseline ambiguity, as the free space phase path R is removed and the unknown baseline determined. The phase path difference for 137 MHz and 411 MHZ is of the order of 19.08 m for 1 TEC unit vertically. The differential carrier phase technique is more sensitive than the Faraday technique, and is hence suitable for the study of finer scale structure irregularities such as the interaction of micropulsations with the ionosphere, possibly one of the chief mechanisms for the transfer of energy to the ionosphere in the auroral regions (Crowley *et al.* 1985, Davies & Hartmann 1976).

For the group path delay, between say 411 MHz and 1233 MHz, the difference is 2.12 m, or a time delay of 7.06 ns for 1 TEC unit. This can be measured directly if some form of coded modulation is used on the beacon transmission. Grubb & Jones (1980) proposed a Pseudo Random Phase Shift Keyed (PSK) modulation digital sequence for routine measurements using the differential group delay method.

If an amplitude modulation of 1 MHz is used, then the differential phase $\Delta\phi$ between a carrier f and its sideband $f + \Delta f$ can be measured on two frequencies and the total electron content determined. Using equation (6), we have (see Eshleman *et al.* 1960), for the phase difference of the modulations

$$\Delta\phi = \frac{8.432 \times 10^{-7} \Delta f}{f^2} \int Nds \text{ radians} \qquad (21)$$

This gives a value for Δf of 26° for 137 MHz and its 1 MHz sideband and 1 TEC unit of ionisation along the path. Depending on the accuracy to which this angle can be measured when compared with the modulation phase difference on a higher frequency, we can obtain a lower sensitivity of the total electron count.

If we now compare the ionospheric electron content, as measured by the Faraday rotation, and the total electron content, as measured by differential carrier phase shift, the protonospheric content may be obtained (see Davies *et al.* 1975). It is also possible to obtain the F Parameter from the

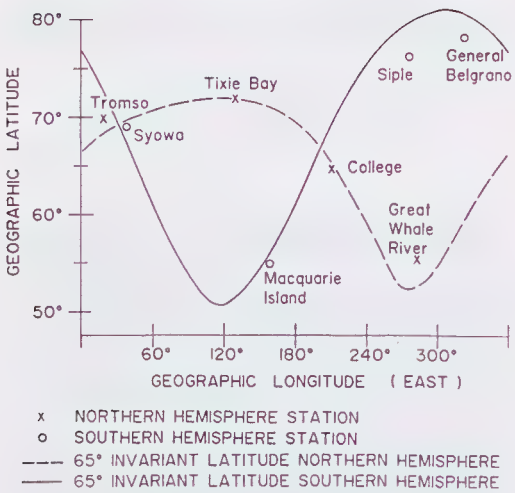

FIG. 1 — Plot showing the location of Macquarie Island in geographic co-ordinates with respect to other Northern and Southern Hemisphere stations and to the 65° N and S invariant latitude.

modulation phase of the Faraday rotation. F is given by

$$F = \int_0^s f_L \, Nds \; / \; \int_0^s Nds \qquad (22)$$

which is the weighted average of the electron gyrofrequency along the ray path;

i.e. $$F = \frac{R \, \Delta f \, \Omega}{\Delta \phi}$$

where R is a frequency dependent constant (see Davies *et al.* 1975).

To obtain the absolute value of the modulation phase, the phases of the transmitted modulations must be known.

SCIENTIFIC RELEVANCE

The techniques outlined above present exciting possibilities for the study of the ionosphere in the Australian Pacific and Asian regions. A receiving station at Macquarie Island would be southernmost in a continuous longitude chain extending from the southern to the northern auroral regions. The proposed AUSSAT beacon would make possible for the first time a detailed study of the whole of the ionosphere, using several different techniques.

Macquarie Island is the most favourable location in the Southern Hemisphere for total electron content studies of the aurora using a geostationary satellite, as its low geographic latitude compared to its geomagnetic latitude means that a higher elevation angle to the satellite is possible, the angle being 28° (see fig. 1). Some of the near earth plasma phenomena which may be studied using the AUSSAT multifrequency beacon, and for which Macquarie Island would provide a very desirable location include

(1) sudden ionospheric disturbances;
(2) ionospheric storms;
(3) travelling ionospheric disturbances and ionospheric gradients;
(4) plasmaspheric content;
(5) micropulsations and their interaction with the ionosphere;
(6) multifrequency scintillations, both phase and amplitude;
(7) mid-latitude trough and the aurora;
(8) interhemispheric asymmetries; and
(9) F region scale heights and ion temperatures.

In particular, Macquarie Island is ideally located for studies of the ionospheric trough (see Lambert *et al.* 1986), features associated with the aurora, large-scale disturbances and their propagation, and such fine-scale effects as micropulsations on the ionosphere. One very interesting study would be that of the plasmaspheric content (see Kersley *et al.* 1978) of the region extending from above the ionosphere around 2500 km to about $L = 4$. The ray path to the satellite extends through several L shells, from $L > 5$ at Macquarie Island, to $L \approx 4$ at the ionospheric point, through $L < 4$ above the ionosphere to the plasmaphase at $L = 4$. A study of the plasmaspheric content variations should reflect the field-aligned diffusive interchange of plasma with the underlying ionosphere in both the local and conjugate hemispheres. Storm-time variations of the ionosphere and plasmasphere from stations extending over a range of latitudes would be a significant contribution to the understanding of ionospheric storm mechanisms. Continuous data will provide a valuable base for updating existing models of the near earth plasma of the region around Macquarie Island.

REFERENCES

CROWLEY, G., WADE, N., WALDOCK, J.A., ROBINSON, T.R. & JONES, T.B., 1985: High time resolution observations of periodic frictional heating associated with Pc5 micropulsations. *Nature*, 316: 538–530.

DAVIES, K., FRITZ, R.B., GRUBB, R.N. & JONES, J.E., 1975: Some early results from the ATS-6 Radio Beacon Experiment. *Radio Sci.*, 10: 785–799.

DAVIES, K. & HARTMANN, G.K., 1976: Short period fluctuations in the total columnar electron content. *J. Geophys. Res.*, 81: 3431–3434.

ESHLEMAN, V.R., GALLAGHER, P.B. & BARTHLE, R.C., 1960: Radar methods of measuring the cislunar electron density. *J. Geophys. Res.*, 65: 3079–3086.

GARRIOTT, O.K., DA ROSA, A.V. & ROSS, W.J., 1970: Electron content obtained from Faraday rotation and phase path length variations. *J. Atmos. Terr. Phys.*, 32: 705–727.

GRUBB, R.N. & JONES, J.E., 1980: Receiver design for a pseudo noise coded radio beacon transmission. *In PROCEEDINGS OF SYMPOSIUM ON SCIENTIFIC AND ENGINEERING USES OF SATELLITE RADIO BEACONS.* Polish Scientific Publishers, Warsaw: 433–442.

KERSLEY, L. & KŁOBUCHAR, J.A., 1978: Comparison of protonospheric electron content measurements from the American and European sectors. *Geophys. Res. Lett.*, 5: 123–126.

LAMBERT, M. & COHEN, E.A., 1986: Monitoring ionospheric irregularities in the southern auroral region by means of a satellite beacon. *Radio Sci.*, 21: 347–350.

ROSS, W.J., 1965: Second order effects on high frequency trans-ionospheric propagation. *J. Geophys. Res.*, 70: 597–612.

TUCKER, A.J. & FANNIN, B.M., 1968: Analysis of ionospheric contributions to the Doppler shift of CW signals from artificial earth satellites. *J. Geophys. Res., Space Phys.*, 73: 4325–4334.

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TOTAL OZONE FLUCTUATIONS OBSERVED AT MACQUARIE ISLAND: 1981–82

by Michael Mallis

(with seven tables and nine text-figures)

MALLIS, M., 1988 (viii): Total ozone fluctuations observed at Macquarie Island: 1981–82. *Pap. Proc. R. Soc. Tasm.*, 122(1): 289–301. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Physics Department, La Trobe University, Bundoora, Victoria, Australia 3083.

It has been possible to show that observed total ozone fluctuations, as measured by a Dobson spectrophotometer at Macquarie Island from November 1981 to October 1982 inclusive, are, for the most part, due to local upper atmospheric perturbations in the lower stratosphere. Total ozone variations resulting from direct solar or geomagnetic influences are only superficially investigated and are not thought to be a major contributing factor.
Key Words: ozone, ozone–weather relationships, total ozone fluctuations, Macquarie Island.

INTRODUCTION

This paper discusses the observed monthly and daily total ozone variations over Macquarie Island, mainly due to meteorological variations; effects due to geomagnetic and solar parameters are only superficially investigated. There have been similar attempts in the past to correlate total ozone with these and other parameters (Pittock 1978, 1983, Weinbeck & Yarger 1978, Dutsch 1979, Chandra & Meada 1980, Natarajan *et al.* 1981, Keating 1981). The meteorological link has for the best part been established (Kulkarni 1968, Pittock 1970, Hartmann & Garcia 1979), although not fully understood, but solar–terrestrial links have shown little promise, with some notable exceptions (Weeks *et al.* 1972, Swider & Keneshea 1973, Crutzen *et al.* 1975, Heath *et al.* 1977, Maeda & Heath 1981).

OZONE THEORY

Although trace quantities of ozone are found in the troposphere, it is mainly found in the stratosphere — more precisely, in the ozonosphere which lies between about 10 and 50 km altitude (see fig. 1). This layer covers the entire Earth and largely governs the thermal structure of the stratosphere. Although it is some 40 km thick, the atmosphere at these altitudes is extremely tenuous. Ozone concentrations are so small that if all the ozone in a vertical column through the entire atmosphere was compressed to sea-level pressure it would form a layer only a few millimetres thick.

Ozone is a very small constituent of the atmosphere, averaging one part in three million. It is formed in the stratosphere by the action of solar ultraviolet radiation and destroyed by some chemical species closer to the ground. The known number of chemical species and reactions which

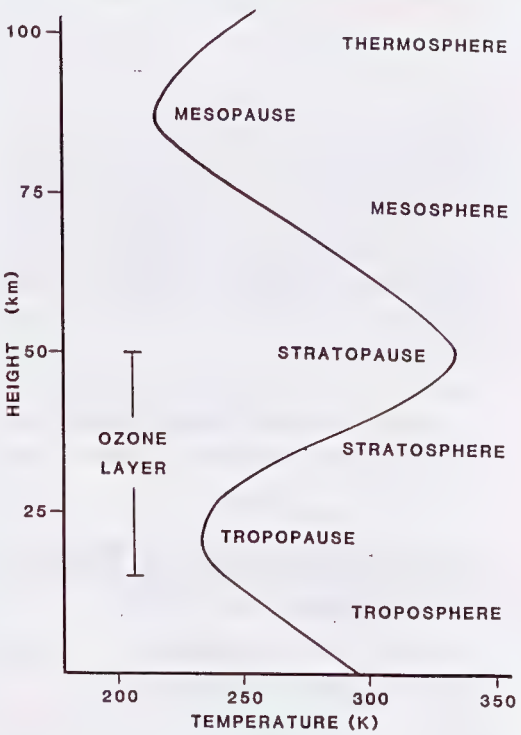

FIG. 1 — Typical variation of temperature with height.

TABLE 1

Monthly means of sunspot number, geomagnetic A_p index and percentage difference between the observed and annual mean total ozone amount over Macquarie Island (1951 to 1960)

Month	Monthly mean		
	Sunspot number	A_p index	% deviation of ozone
Nov 1981	137.5	15	-9.3
Dec	150.1	10	-10.6
Jan 1982	111.2	12	0.6
Feb	163.6	33	-4.4
Mar	153.8	18	-16.9
Apr	122.0	22	-9.7
May	82.2	17	-1.2
Jun	110.4	22	-18.2
Jul	106.1	30	-10.8
Aug	107.6	21	-7.4
Sep	118.8	36	-8.4
Oct	94.3	18	-9.3

govern ozone creation and destruction in the atmosphere is of the order of 150. More than 99% of the incident energy in sunlight for wavelengths less than about 300 nm is absorbed by ozone. The simplest set of reactions involving ozone formation and destruction was first described by Chapman (1930) and involved two active species, O_3 and O_2. For wavelengths shorter than 240 nm the following reaction occurs:

$$O_2 + h\nu \rightarrow O + O \qquad (1)$$

Further to reaction (1), atomic and molecular oxygen may react in a three-body reaction to form ozone; this is given by

$$O + O_2 + M \rightarrow O_3 + M \qquad (2)$$

For wavelengths shorter than 1100 nm, but mostly in the "Hartley" and "Huggins" bands, ozone is dissociated by

$$O_3 + h\nu \rightarrow O_2 + O \qquad (3)$$

Ozone can be destroyed by

$$O_3 + O \rightarrow O_2 + O_2 \qquad (4)$$

and

$$O_3 + O_3 \rightarrow O_2 + O_2 + O_2 \qquad (5)$$

Reaction (5) is due to thermal decomposition. All of the above reactions, and others, lead to establishing an "active" equilibrium in ozone concentration for various layers of the stratosphere.

Ozone diffuses downwards due to ozone/air gradients and to large-scale horizontal and vertical turbulence. Once ozone reaches the troposphere, it rapidly mixes with air in the troposphere and is diffused. Conversely, species such as H_2O, CH, NO_x, ClO_x, and others, make their way into the stratosphere, where they are involved in reactions that destroy ozone. Some of these species occur naturally, whilst others are of anthropogenic origin.

TOTAL OZONE OBSERVATION

Studies on ozone–weather relationships in general show a good correlation with some meteorological parameters in the upper troposphere and lower stratosphere (Dobson & Harrison 1926, Kulkarni 1966, Natarajan *et al.* 1981). Often, total ozone can deviate considerably from the annual mean on individual days, mostly due to short-term atmospheric perturbations which redistribute ozone.

Photochemical processes cannot explain the day-to-day changes in total ozone at all altitudes in the atmosphere; these are due to dynamic processes operating in the lower stratosphere. The photochemical restoration time in the high stratosphere is short, about a few hours, and so any changes in the local total ozone due to dynamical effects are quickly corrected. The ozone lifetime in the troposphere is also short, due to rapid mixing to the surface where it is destroyed. It is in the lower stratosphere, where the restoration time for ozone is in the order of days to months, that dynamic processes can account for the observed total ozone variations.

This section investigates both the observed monthly and daily total ozone variations over Macquarie Island in relation to meteorological, some geomagnetic and solar parameters. All ozone measurements were made with a Dobson spectrophotometer which measures (up to 2% accuracy in ideal conditions) total ozone in a vertical column of the atmosphere (Komhyr 1980).

On the whole, except for January and May, there was significantly less total ozone than in the longer-term mean observed over Macquarie Island (table 1). Why this should be so is not immediately apparent from the small data base used. There may, indeed, be a direct solar influence, but no pattern is evident. Ideally, a larger data base spanning a few solar cycles would form the basis

for further work. Similarly, any relationship between the A_p index and total ozone is not readily apparent for much the same reasons as for the sunspot number.

Even though no relationship can be readily observed between total ozone and sunspot number or A_p index values, this does not mean that none exists. For example, some solar activity may affect only certain levels of the stratosphere and can be masked by total ozone measurements. In fact the half-restoration time for ozone formation increases from the order of days in the lower stratosphere to hours in the upper stratosphere. The high stratosphere, for example, may be influenced by solar activity, since the duration of solar flares is comparable with the half-restoration time of ozone (Heath *et al.* 1977, Meada & Heath 1981). Lower in the stratosphere, however, it becomes more dificult to recognise cause-and-effect solar-induced phenomena, because of the greater role of atmospheric transport processes in the longer time-scales involved. Paetzold (1973) claimed evidence that ozone in the upper stratosphere is modulated by the solar sunspot cycle. Others like Ahmed & Halim (1961) could find no statistical basis to confirm the existence of any relationship between total ozone and sunspots or geomagnetic activity.

Figures 2 to 4 inclusive show tropopause temperature, pressure and height, with total ozone as a function of time, in days, for the months November 1981 to October 1982 respectively. Day-to-day variations in total ozone are readily observed; it is apparent that for some months the tropopause is related to this change. A cross-correlation analysis between total ozone and all three tropopause variables was made to check if any strong relationship exists. Note that, in all subsequent correlation studies involving total ozone, the ozone data were first detrended by having the annual variation removed. Also any gap in the data was filled in by averaging around the missing point. This is necessary in cross-correlation analysis of this kind before meaningful results can be obtained. Each of figures 5 to 7 show four seasonal plots of the correlation coefficient as a function of lag time (in days) between total ozone and each of tropopause temperature, pressure and height respectively. Graphs (A) are for the summer months (December, January, February), whilst graphs (B), (C) and (D) are for the autumn (March, April, May), winter (June, July, August) and spring (September, October, November) months respectively. Table 2 summarises these findings.

From table 2 it is observed that the correlation between total ozone and tropopause temperature for all seasons is less meaningful, if at all significant, than correlations with tropopause pressure and height. Tropopause height and total ozone correlation is good for all seasons, but especially so for spring when ozone has reached its annual maximum. Why total ozone should correlate marginally better with tropopause height than with tropopause pressure or temperature is unknown. The fact that lag time for tropopause height and total ozone correlation is about 0.7–0.9 days is subtle evidence that lower stratospheric/upper tropospheric dynamic changes are taking place, since relaxation times for the recovery of ozone depletions or enhancements are in the order of days at these altitudes. On the basis of these data, there appears to be no significant seasonal trend in correlation of total ozone with the tropopause, except that summer and spring yield respectively the lowest and highest correlation coefficients. Kulkarni (1968) supports this view and further claims that for Macquarie Island there is no long-term relationship between total ozone and the tropopause. However, Kulkarni also states that, even though there is no seasonal variation in the tropopause, there does exist a good short-term correlation variation in the order of days. This implies that the mechanisms responsible for the day-to-day changes in total ozone are quite different from seasonal changes. Horizontal advection of ozone-rich air, travelling longitudinally and not involving vertical motions of the atmosphere above the tropopause, could also be responsible for these variations. It now needs to be investigated if atmospheric variations above the tropopause, due to atmospheric circulation, are also involved in ozone fluctuations.

Another test of short-term ozone variability is to see how well this correlates with the upper troposphere and lower stratosphere temperature and height variations for certain geopotential pressure levels (tables 3 and 4).

TABLE 2

Seasonal correlation coefficients and lag times in days (in brackets) between total ozone and tropopause

Season	Correlation coefficients and lag times		
	Temperature	Pressure	Height
Summer	0.15(-0.2)	0.44(-0.7)	-0.48(-0.75)
Autumn	0.18(-0.9)	0.56(-0.7)	-0.63(-0.9)
Winter	0.40(-0.95)	0.49(-0.9)	-0.56(-0.9)
Spring	0.55(-0.7)	0.67(-0.7)	-0.72(-0.7)

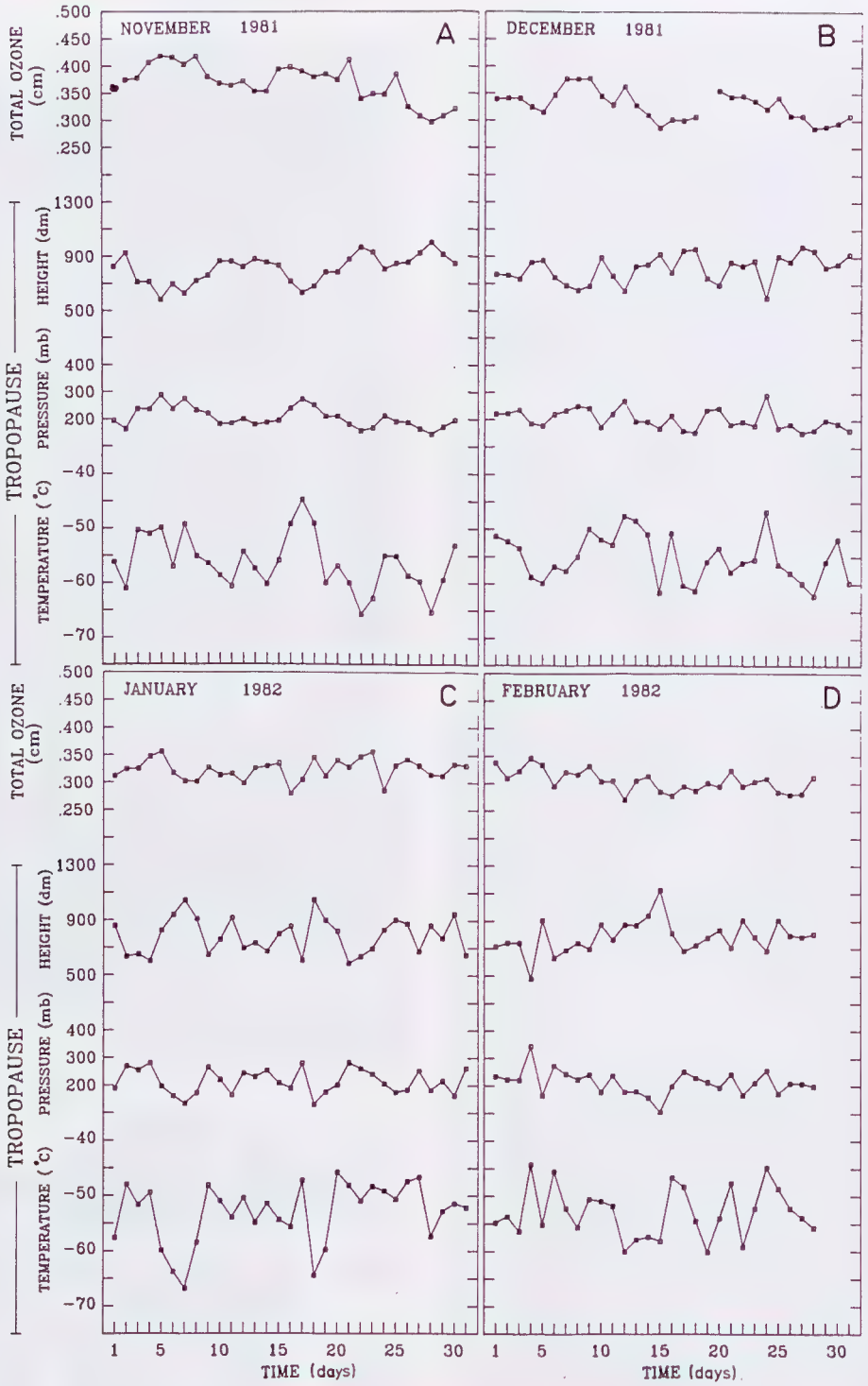

FIG. 2 — Time cross-section of total ozone (Dobson number = 78) and tropopause pressure, height and temperature for November 1981 to February 1982.

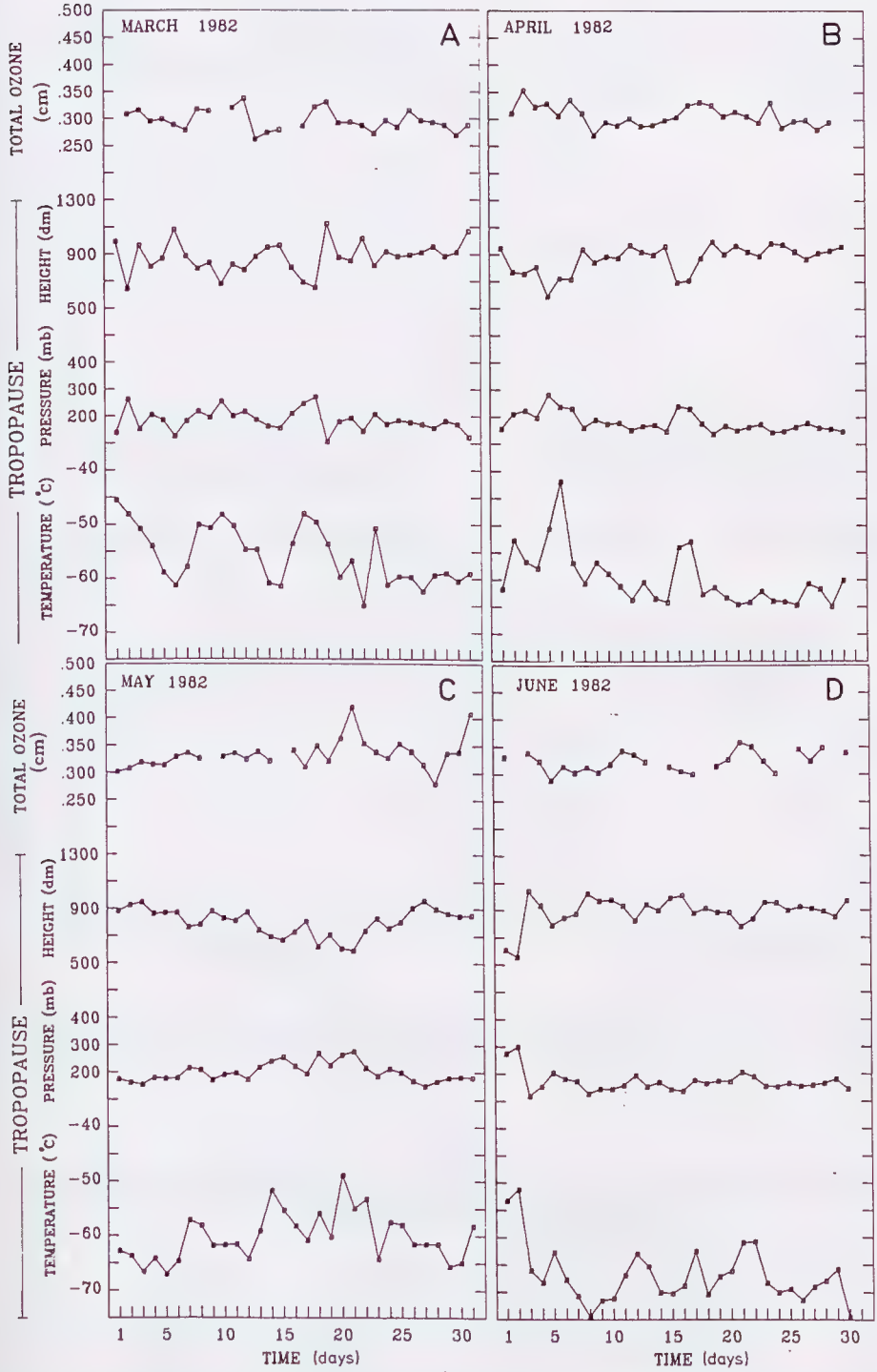

FIG. 3 — Time cross-section of total ozone (Dobson number = 78) and tropopause pressure, height and temperature for March-June 1982.

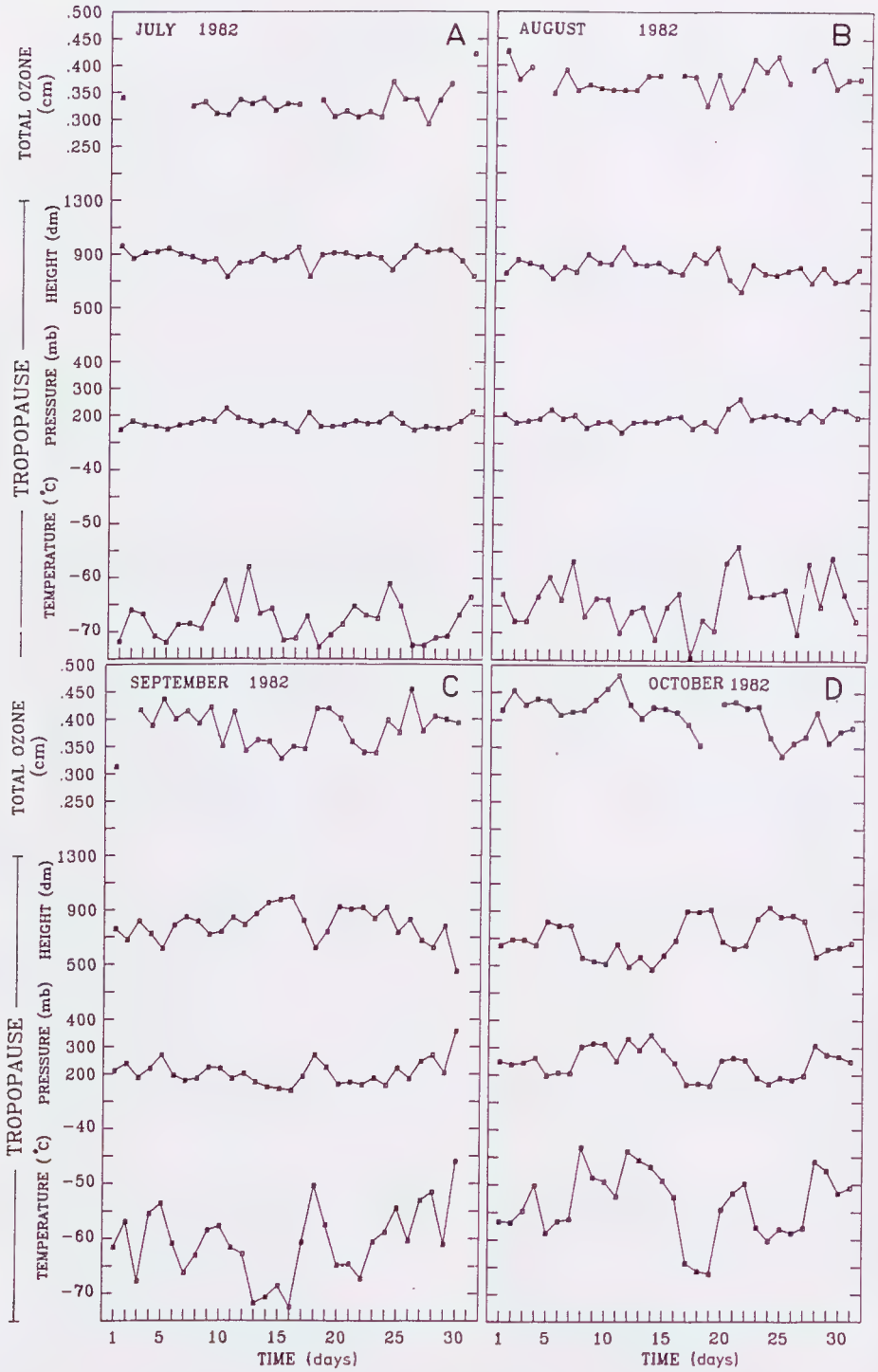

FIG. 4 — Time cross-section of total ozone (Dobson number = 78) and tropopause pressure, height and temperature for July–October 1982.

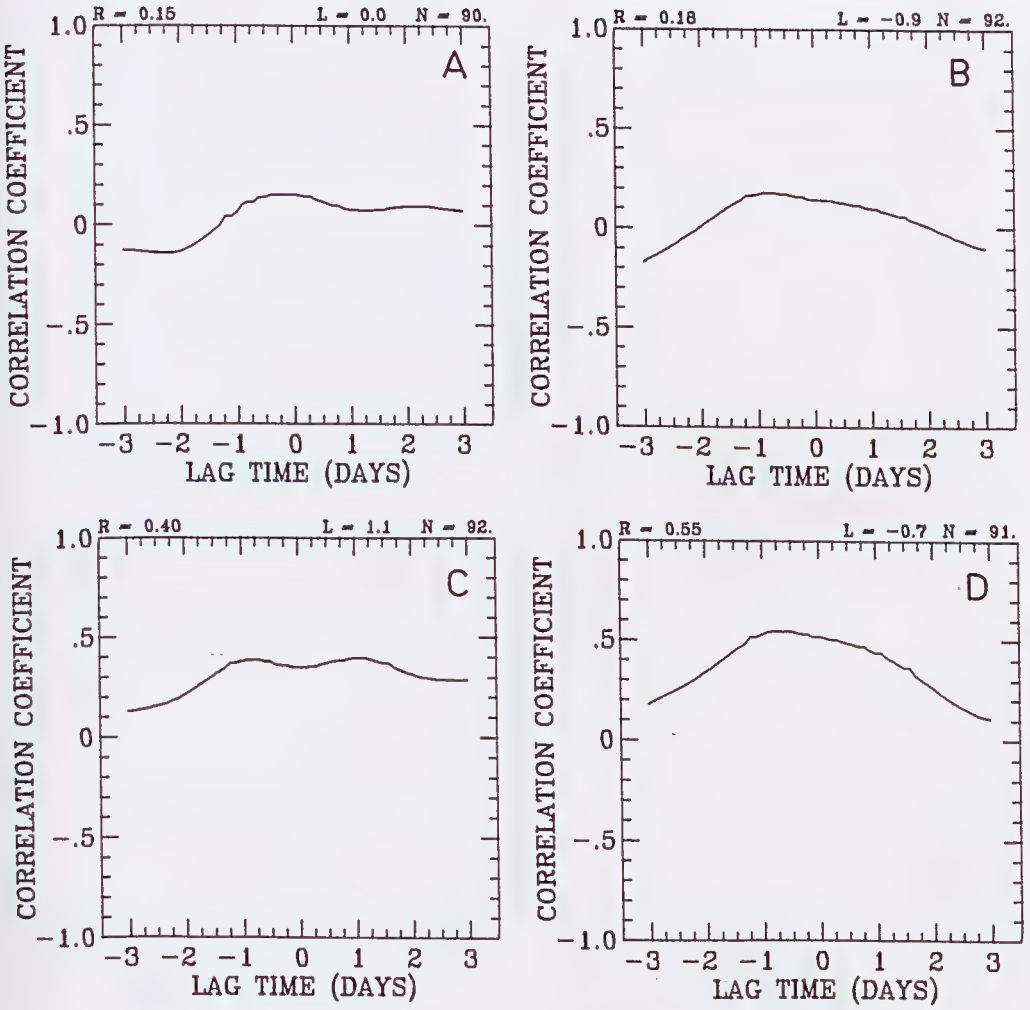

FIG. 5 — Graphs of correlation coefficient as a function of lag time between total ozone and tropopause temperature for (A) summer, (B) autumn, (C) winter and (D) spring.

TABLE 3

Seasonal correlation coefficients and lag times in days (in brackets) between total ozone and geopotential temperature

Season	Correlation coefficients and lag times				
	500 mb	300 mb	200 mb	100 mb	50 mb
Summer	-0.61(-0.5)	-0.56(-1.0)	0.31(-0.4)	0.76(-0.9)	0.75(-0.7)
Autumn	-0.73(-0.2)	-0.64(-0.5)	0.10(-0.2)	0.0(-0.7)	-0.39(-0.5)
Winter	-0.55(1.8)	-0.50(2.8)	0.37(0.9)	-0.19(-0.7)	0.9(-0.4)
Spring	-0.67(-0.5)	-0.14(0.5)	0.54(-0.5)	0.55(-0.4)	0.32(-1.9)

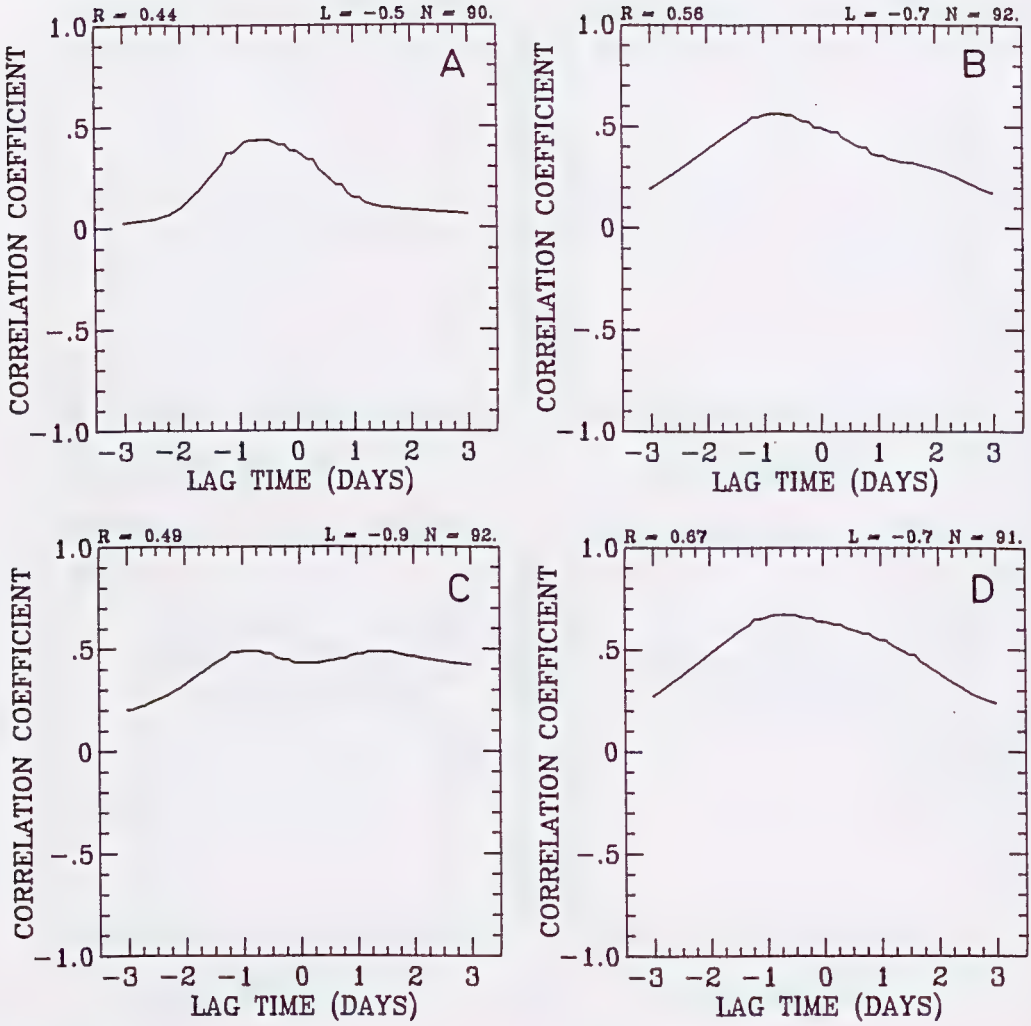

FIG. 6 — Graphs of correlation coefficient as a function of lag time between total ozone and tropopause pressure for (A) summer, (B) autumn, (C) winter and (D) spring.

From table 3 it is apparent that correlation coefficients and lag times look very consistent at the 500 mb, 300 mb (except for spring) and 200 mb levels. There are sign changes at the 100 mb and 50 mb levels during the winter and autumn months. This could be due to the inherent fewer data points used in the analysis for these months when it was more difficult to obtain many measurements. Reasonable correlations are evident for the upper troposphere at the 500 mb level, except for winter and spring when ozone is on the increase. However, the tropopause does not reflect the same level of correlation. The only other time that there is any good correlation is in summer, at the 100 mb and 50 mb pressure level. Lower stratospheric height variations at this time could be attributed to the passage of high level troughs which are not reflected in the lower troposphere. These troughs seem to cause a lowering of ozone at these levels, which is only partially seen in the total ozone. Kulkarni (1968) reports a similar observation. He also reports that temperature variations of pressure levels in the lower stratosphere can be independent of each other. Unfortunately, umkher measurements, which yield a vertical ozone profile, are not available for 1981–82, due to incorrect recording practices, and so a check on this result is not possible.

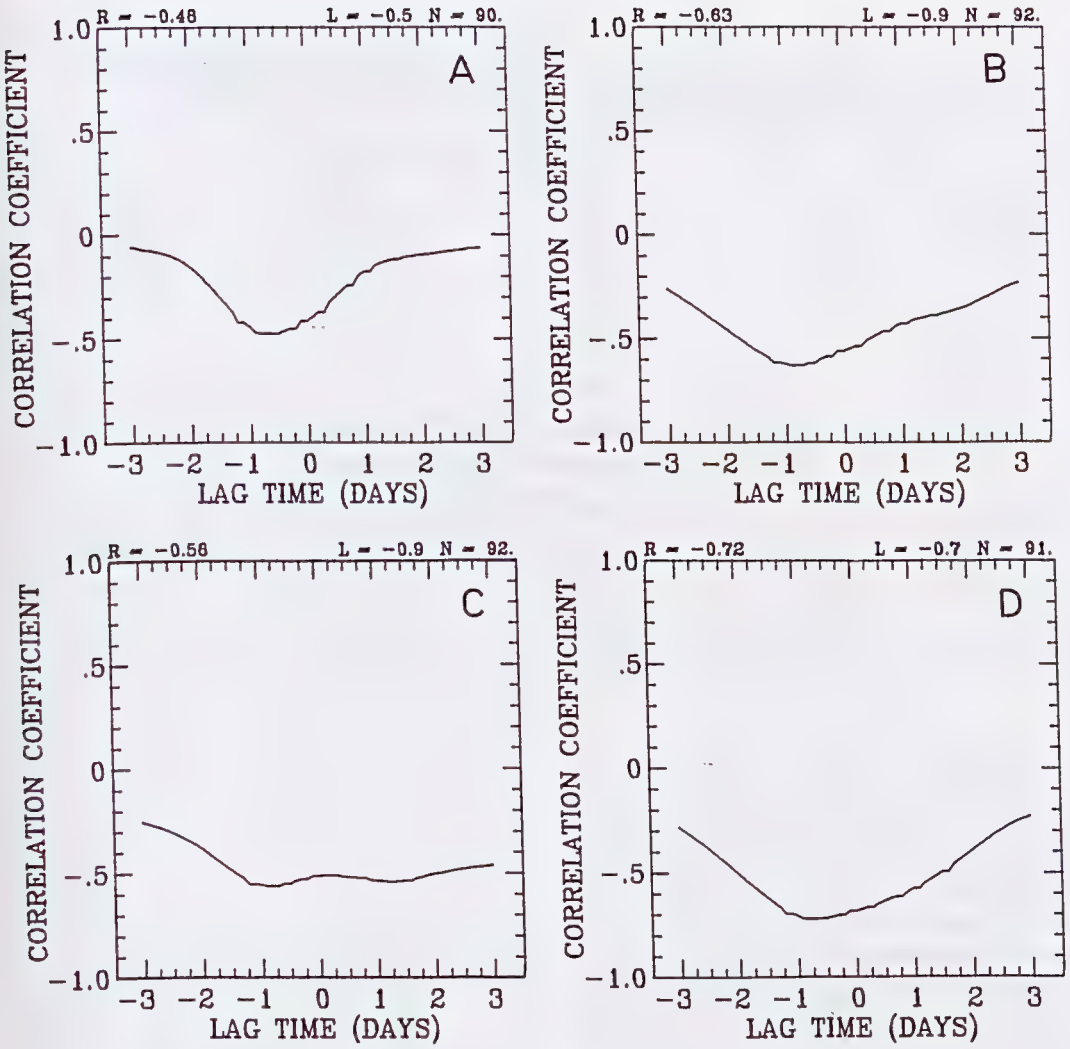

FIG. 7 — Graphs of correlation coefficient as a function of lag time between total ozone and tropopause height for (A) summer, (B) autumn, (C) winter and (D) spring.

TABLE 4

Seasonal correlation coefficients and lag times in days (in brackets) between total ozone and geopotential height

Season	Correlation coefficients and lag times				
	500 mb	300 mb	200 mb	100 mb	50 mb
Summer	-0.61(-0.5)	-0.65(-0.5)	-0.72(-0.7)	-0.76(-0.7)	-0.37(-0.7)
Autumn	-0.73(-0.5)	-0.77(-0.5)	-0.82(-0.5)	-0.80(-0.5)	-0.72(-0.2)
Winter	-0.60(-0.5)	-0.59(-0.5)	-0.58(-0.5)	-0.41(-0.5)	-0.29(0.1)
Spring	-0.78(-0.9)	-0.77(-0.7)	-0.70(-0.7)	-0.41(-0.9)	-0.19(-0.2)

TABLE 5

Seasonal correlation coefficients and lag times in days (in brackets) between total ozone and the north-south geopotential wind component

Season	Correlation coefficients and lag times			
	500 mb	300 mb	200 mb	100mb
Summer	-0.14(2.1)	-0.19(2.2)	0.17(-1.5)	0.23(-2.5)
Autumn	-0.07(2.2)	0.16(-3.0)	0.18(-3.0)	0.26(-3.0)
Winter	-0.12(1.9)	0.13(-1.3)	0.14(-0.7)	-0.17(2.5)
Spring	-0.11(1.6)	0.18(-2.3)	0.18(-2.2)	0.17(-2.5)

TABLE 6

Seasonal correlation coefficients and lag times in days (brackets) between total ozone and the east-west geopotential wind component

Season	Correlation coefficients and lag times			
	500 mb	300 mb	200 mb	100 mb
Summer	-0.16(-3.0)	-0.26(-2.9)	-0.21(-2.7)	-0.20(-3.0)
Autumn	-0.05(-1.9)	-0.15(-2.8)	-0.13(-2.5)	-0.15(-2.7)
Winter	0.16(-0.2)	0.17(0.3)	0.12(0.4)	0.13(-1.9)
Spring	-0.13(-2.1)	-0.21(-22.7)	-0.15(-2.8)	-0.17(-2.8)

From table 4 it is readily observed that, in the lower stratosphere, there is a far better correlation, for all seasons, between total ozone and geopotential height variations than with temperature or pressure. The 50 mb level displays a poorer correlation whilst lag times are consistent and within 0.8 days of each other. The only other noticeable trend, although probably not significant, is that lag times range from 0.9 to 0.7 days in spring, when ozone levels are at their heighest, to 0.5 days in autumn and winter, when ozone is least abundant. It is tempting to conclude from this that travelling stratospheric waves are mostly responsible for vertical lifting and sinking of the atmosphere, producing a corresponding lessening and rise in total ozone. This supposition is unvalidated by the limited available data for the period of study, but Pittock (1970) presents a case to strongly support this.

A test on the variation of total ozone with upper atmosphere wind systems should reveal to what extent, if any, horizontal advection of ozone-rich/poor air is responsible. An analysis of 500 mb, 300 mb, 200 mb and 100 mb winds reveals no statistical significance. Tables 5 and 6 list correlation coefficients and lag times as a function of season for north-south and east-west geopotential winds respectively. The poor correlation and variability of lag times for all seasons discount the

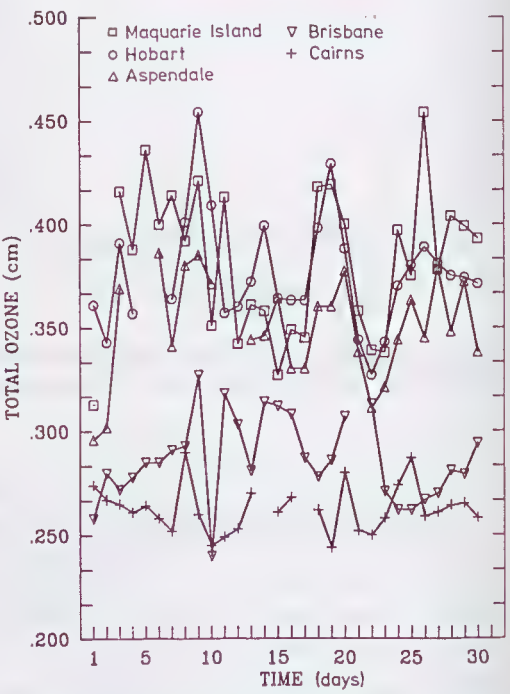

FIG. 8 — Total ozone for September 1982, as observed over Macquarie Island, Hobart, Aspendale, Brisbane and Cairns.

possibility that horizontal advection of ozone is responsible for most observed ozone fluctuations.

An example of a low pressure system significantly modifying total ozone over a wide latitudinal range is presented in figure 8, which depicts five plots of total ozone, for Macquarie Island, Hobart, Aspendale, Brisbane and Cairns for September 1982. Of interest is the period from 16 to 24 September, when Macquarie Island, Hobart and Aspendale experienced a sharp rise in total ozone on about 19 September and a subsequent depression, reaching a minimum on 22 September. A further rise was experienced until 24 September, where the three ozone plots follow a similar pattern, albeit with an increasing phase shift in time of about two and three days respectively. Meteorological records show that a series of low pressure systems began passing Macquarie Island on 15 September and passed over by 19 September. Thereafter, until 21 September, a high pressure system dominated (Fig. 9). This was followed by another series of complex low pressure systems. These synoptic data coincide exactly with observed total ozone variations at Macquarie Island for the same period. Both tropopause and higher geopotential pressure level temperatures and heights follow the same pattern. This is a good example of how a passing pressure system can significantly modify the total ozone profile because of lower stratospheric travelling waves, particularly as the observed pressure variations influenced total ozone over such a wide latitudinal range and were not just a local effect. Such day-to-day variations in total ozone are not explained by photochemical theory, but are more readily explainable as being due to simple dynamical redistribution of ozone on a small or large scale.

Short-term total ozone variations superimposed on seasonal ozone variations produce ozone profiles as in figures 2, 3 and 4. These small fluctuations are for the most part simply a result of the atmosphere heaving up or down with the passage of high or low pressure systems, causing a corresponding decrease or increase in total ozone.

A correlation analysis between total ozone and the mean westerly zonal index (from 35–55° latitude and 100–175° longitude) is summarised in table 7. Both correlation coefficients and, especially, lag times are highly variable, and no readily discernible pattern appears. The spring months notably produce some very good correlations, but there is great variability in lag times from –3 to 0.3 days. Although horizontal advection may indeed play a major role in redistributing ozone, either on a short- or long-term basis, this cannot be demonstrated at present. The cited example of springtime correlation, if interpreted further, may indicate otherwise.

TABLE 7

Correlation coefficients and lag times in days (in brackets) between total ozone and westerly zonal index (35–55° latitude and 100–175° longitude)

Month	Correlation coefficients and lag times
Nov 1981	0.85(-3.0)
Dec	0.2 (1.0)
Jan 1982	0.18(0.0)
Feb	0.65(0.0)
Mar	0.45(-0.9)
Apr	0.52(1.1)
May	0.58(2.2)
Jun	0.52(0.3)
Jul	0.29(-1.3)
Aug	0.49(-3.0)
Sep	0.69(-1.4)
Oct	0.72(0.3)

CONCLUSIONS

It can be demonstrated that total ozone fluctuations on a short-term scale are mostly correlated to similar variations in various upper atmospheric meterological parameters. Some day-to-day variations are explainable by interpreting such data as possibly due to vertical air movements resulting from upper tropospheric/lower stratospheric wave motions. Whether horizontal advection of ozone-rich/poor air is responsible cannot be decided on the limited data base available. Unfortunately, ozone profiles, as obtained by the umkher method, are not available for the time period of interest; study of these would have gone some way in determining how the ozone layer is being modified. Variations in ozone as a result of some solar–terrestrial parameters have proved negligible.

ACKNOWLEDGEMENTS

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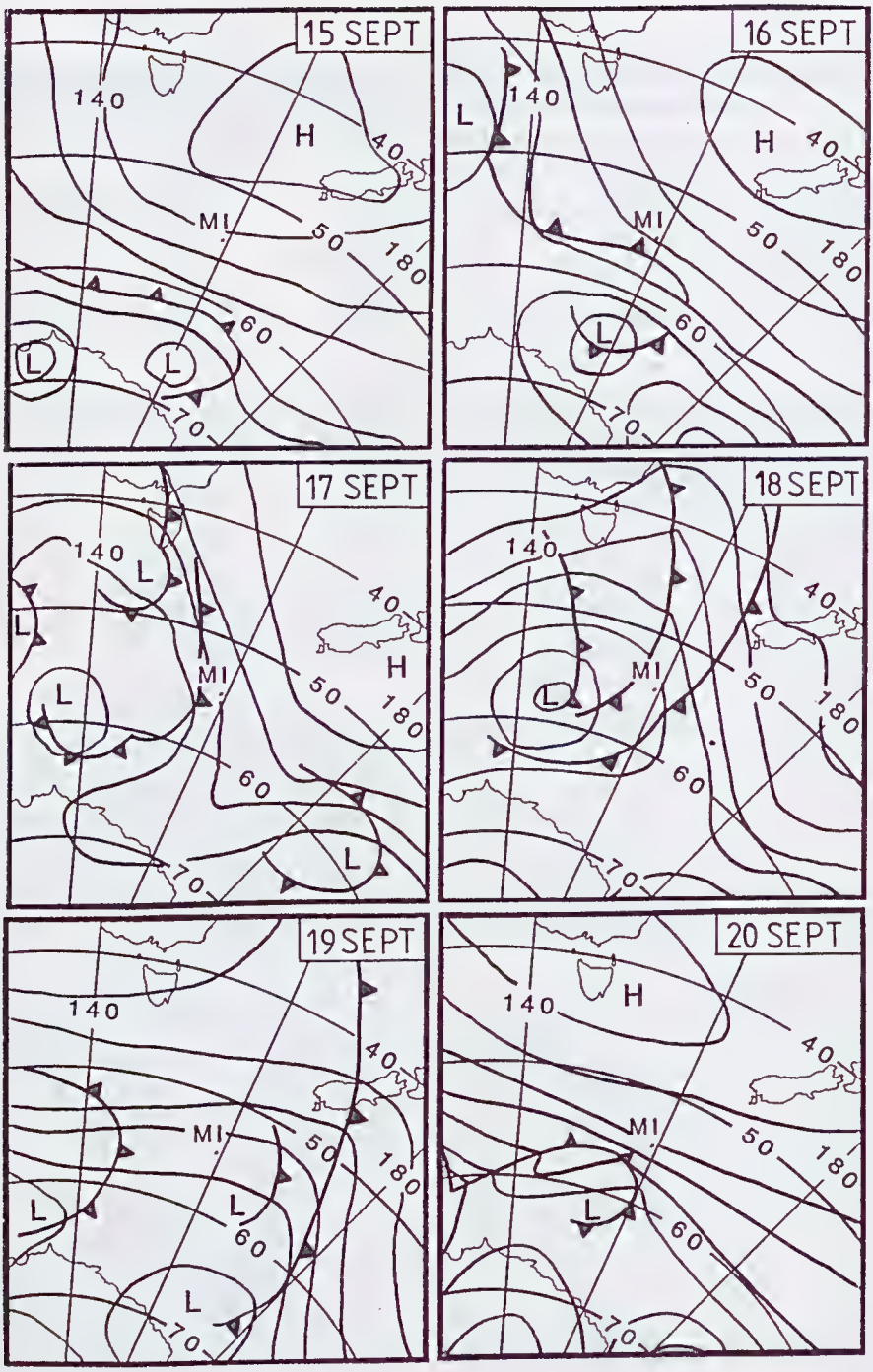

FIG. 9 — Synoptic maps centred on Macquarie Island (MI) showing the passage of pressure systems of interest at 00 UT from 15–20 September 1982.

REFERENCES

AHMED, S.J. & HALIM, A., 1961: Total atmospheric ozone and geomagnetic activity. *J. Geophys. Res.*, 66: 3213–3218.

CHANDRA, S. & MEADA, K., 1980: A search for correlation between geomagnetic activity and stratospheric ozone. *Geo. Res. Lett.*, 7: 757–760.

CHAPMAN, S., 1930: A theory of upper atmospheric ozone. *Quart. J. R. Met. Soc.*, 3: 103.

CRUTZEN, P.J., ISAKSEN, I.S.A. & REID, G.C., 1975: Solar proton events: stratospheric sources of nitric oxide. *Science*, 189: 457–459.

DOBSON, G.M.B. & HARRISON, D.N., 1926: Measurement of the amount of ozone in the Earth's atmosphere and its relation to other geophysical conditions. *Proc. R. Soc. Lond.*, 110: 660–693.

DUTSCH, H.U., 1979: The search for solar cycle–ozone relationships. *J. Atmos. Terr. Phys.*, 41: 771–785.

HARTMANN, D.L. & GARCIA, R.R., 1979: A mechanistic model of ozone transport by planetary waves in the stratosphere. *J. Atmos. Sci.*, 36: 350–364.

HEATH, D.F., KRUEGER, A.J. & CRUTZEN, P.J., 1977: Solar proton event: influence on stratospheric ozone. *Science*, 197: 886–888.

KEATING, G.M., 1981: The response of ozone to solar activity variations: a review. *Sol. Phys.*, 74: 321–347.

KOMHYR, W.D., 1980: *OPERATIONS HANDBOOK — OZONE OBSERVATIONS WITH A DOBSON SPECTROMETER.* NDAA Environment Research Laboratories, Air Resources Laboratory, Boulder, Colorado.

KULKARNI, R.N., 1966: The vertical distribution of atmospheric ozone and possible transport mechanisms in the stratosphere in the southern hemisphere. *Quart. J. R. Met. Soc. Lond.*, 92: 363–373.

KULKARNI, R.N., 1968: Ozone fluctuations in relation to upper air perturbations in the middle latitudes of the southern hemisphere. *Tellus*, XX(2): 305–313.

MAEDA, K. & HEATH, D.F., 1981: Stratospheric ozone response to a solar proton event: hemispheric asymmetries. *Pure Appl. Geophys.*, 119: 1–8.

NATARAJAN, M., CALLIS, L.B. & NEALY, J.E., 1981: Solar variability: effects on stratospheric ozone, trace constituents and thermal structure. *Pure Appl. Geophys.*, 119: 750–779.

PAETZOLD, H.K., 1973: The influence of solar activity on the stratospheric ozone layer. *Pure Appl. Geophys.*, 106: 1308–1311.

PITTOCK, A.B., 1970: Ozone behaviour associated with the middle stratospheric circulation during the southern spring of 1967. *Quart. J. R. Met. Soc.*, 96(408): 208–225.

PITTOCK, A.B., 1978: A critical look at long-term sun–weather relationships. *Rev. Geophys. Space Phys.*, 16: 400–420.

PITTOCK, A.B., 1983: Solar variability, weather and climate: an update. *Quart. J. R. Met. Soc.*, 109: 23–55.

SWIDER, W. & KENESHEA, T.J., 1973: Decrease of ozone and atomic oxygen in the lower mesosphere during a PCA event. *Planet. Space Sci.*, 21: 1969–1973.

WEEKS, L.H., CUIKAY, R.S. & CORBIN, J.R., 1972: Ozone measurements in the mesosphere during the solar proton event of 2 November 1969. *J. Atmos. Sci.*, 29: 1138.

WEINBECK, R.S. & YARGER, D.N., 1978: Relationships of world atmospheric ozone profiles to solar magnetic field activity. *Pure Appl. Geophys*, 116: 32.

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PIB AND PI2 GEOMAGNETIC PULSATIONS AT AURORAL BREAK-UP

by I.F. Grant, G.B. Burns and K.D. Cole

(with six text-figures)

GRANT, I.F., BURNS, G.B. and COLE K.D., 1988 (viii): PiB and Pi2 geomagnetic pulsations at auroral break-up. *Pap. Proc. R. Soc. Tasm.*, 122(1): 303–311. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080–4703. Antarctic Division, Department of Science, Kingston, Tasmania, Australia 7150; and Division of Theoretical and Space Physics, La Trobe University, Bundoora, Victoria, Australia 3083.

The potential of optical and magnetic data collected at Macquarie Island for determining the origin of PiB and Pi2 classes of geomagnetic pulsations is discussed. The current state of knowledge of the physical processes behind the auroral substorm and these associated geomagnetic pulsations is outlined. Preliminary results based on one month's data are presented. The diurnal distribution of frequency of occurrence of PiB and Pi2 indicates that Pi2 propagate longitudinally 30–40° further than do PiB. The frequency with which each type of event is associated with auroral intensification also shows the greater range of Pi2. It is suggested that Pi2 and PiB have the same generation mechanism, that PiB are observed only at short distances from their source and that Pi2 are seen far from their source and are PiB with their higher frequencies removed during propagation.

Key Words: geomagnetic pulsations, auroral substorms, Macquarie Island.

INTRODUCTION

Geomagnetic pulsations are small disturbances in the earth's magnetic field with time-scales of seconds or minutes. Their amplitude is of the order of one part in 10^4 of the background field and they often appear as quasi-sinusoidal oscillations. The magnetic pulsations are either hydromagnetic waves originating in disturbances in the magnetosphere or the magnetic signature of currents in or near the ionosphere. Because any electric current produces a magnetic field in the surrounding space, magnetic pulsations observed at the ground are potentially a good diagnostic tool for studying currents in the earth's ionosphere and magnetosphere. For this reason it is worthwhile identifying the sources of the various classes of magnetic pulsations.

The two important classes of pulsation which accompany sudden intensifications of aurora in late evening and around magnetic midnight are known as Pi2 and PiB (fig. 1). The two are closely related. A Pi2 waveform is a train of damped oscillations of period 40 to 150 seconds with an impulsive onset. Though observed in daytime and at mid- and low latitudes, their activity is strongest at high latitudes at night (review by Saito 1969). PiB pulsations occur only at auroral latitudes and near magnetic midnight (Saito 1969). PiB often have a strong Pi2 component, but in addition higher frequency pulsations (periods down to one second) are also present. Thus PiBs' spectrum is very broad and their waveform is quite irregular. PiB are also characterised by a very abrupt onset and a duration of only a few minutes, the "B" in their name standing for "burst".

PiB and Pi2 pulsations are of interest because they are intimately associated with the initiation of the auroral magnetic substorm, one of the most important processes by which energy and energetic particles are dumped into the ionosphere. For both classes of pulsation, the generation of the magnetic disturbance and the mechanism of its propagation away from the source region are unresolved questions. The main question regarding their generation is whether the ultimate source is the substorm current system or the precipitation of energetic electrons which is associated with the substorm. The first proposal holds that the magnetic disturbance which is a PiB or Pi2 is the magnetic field of the fluctuating field-aligned currents which couple the ionosphere and magnetosphere during substorms (Wilhelm *et al.* 1977, Bosinger *et al.* 1981). A key feature of some current system theories is that the periodicity of the Pi2 derives from the field-aligned current's being carried by a transverse hydromagnetic wave travelling along closed field lines and bouncing between hemi-

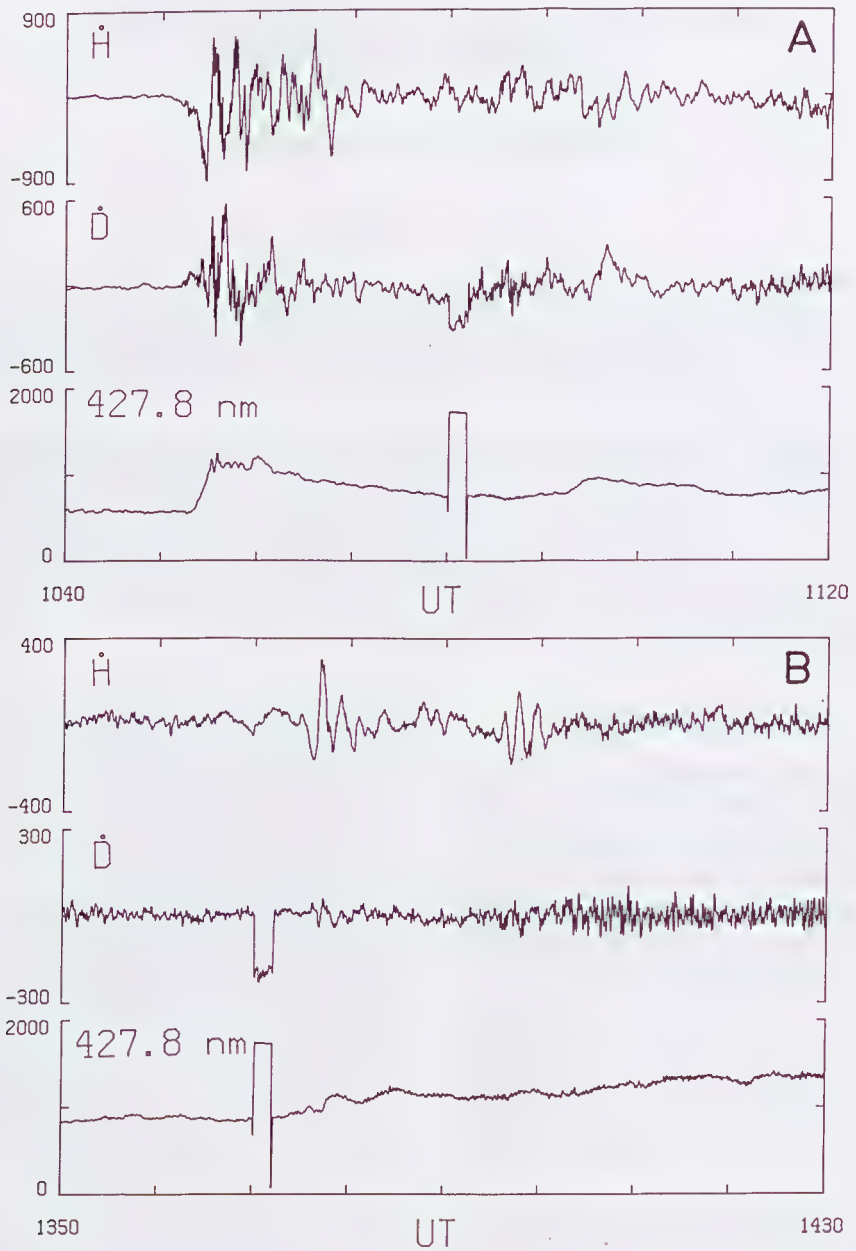

FIG. 1 — (A) PiB onset at 1047 UT (Macquarie Island, 29/10/86). The artefacts in the D and photometer traces at 1100 UT are time marks. The units on the vertical axes are arbitrary on these plots and the others in this paper, the Macquarie Island H and D units being very close to equal. (B) Pi2 trains (Macquarie Island, 2/12/86).

spheres (review by Baumjohann & Glassmeier 1984). In the other view, fluctuations in the energetic precipitation may give rise to magnetic effects indirectly by modulating the conductivity of the ionosphere and hence ionospheric current (Fukunishi & Hirasawa 1970, Heacock & Hunsucker 1977, Haldoupis *et al.* 1982, Dovbnya *et al.* 1983). For the propagation of the pulsations from auroral to lower latitudes both ionospheric (Rostoker 1965, Fukunishi & Hirasawa 1970, Kikuchi & Araki 1979) and magnetospheric (Fukunishi & Hirasawa 1970, Sutcliffe 1975, Southwood & Stuart 1979) paths have been proposed.

AURORAL SUBSTORM BACKGROUND

PiB and Pi2 activity maximises at the latitude of the auroral electrojet (Olson & Rostoker 1975). The electrojet is the band of intense ionospheric current flowing in the auroral zone, predominantly eastward in the evening and westward in the morning. The boundary between the eastward and westward electrojets is located in the late evening to midnight sector and is known as the Harang discontinuity. That part of the auroral zone is of interest here as it is the region of the break-up phase of polar magnetic substorms. Early in the night, the aurora is in the form of quiet arcs aligned east–west. At the onset of a substorm the auroral arcs brighten and distort. This is the break-up or expansive phase. It lasts only several minutes and produces the most dramatic auroral displays. The disturbance starts in a localised area and expands in all directions, spreading poleward not continuously but by a sequence of impulsive leaps. It has been found that maximum PiB and Pi2 amplitudes coincide in time and position with these successive intensifications (Olson & Rostoker 1975). During the subsequent recovery phase of the substorm the aurora generally takes the fainter patchy pulsating form, which may last several hours and gives rise to the long-lasting and irregular PiC magnetic pulsations, usually in the morning sector (Akasofu 1968).

The widely accepted theory for the substorm holds that it is triggered in the tail of the magnetosphere (Nishida 1978). As the solar wind flows past the earth it sweeps the nightside magnetic field lines from a closed dipolar shape to the drawn out and open tail configuration. Lying roughly in the plane of the geomagnetic equator and separating the oppositely directed components of the tail field is a thin sheet of electric current directed across the tail

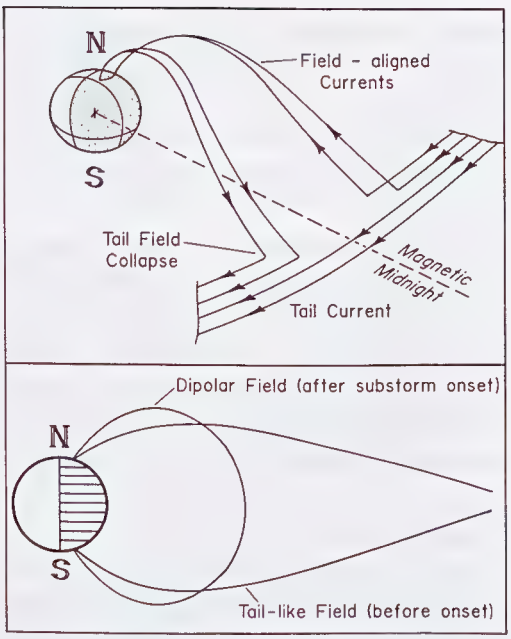

FIG. 2 — (A) The substorm current system. (B) Configuration of the field lines of the inner magnetotail before and after substorm onset (adapted from Baumjohann & Glassmeier 1984).

from dawn to dusk. At the onset of a substorm part of the cross-tail current is short-circuited, by a still unknown mechanism, through the ionosphere in the auroral zone near magnetic midnight via the magnetic field lines (fig. 2) (McPherron *et al.* 1973). This causes the innermost field lines of the magnetotail to close and become dipolar, suddenly releasing energy and particles stored in the tail and dumping them into the auroral ionosphere. Thus a current wedge is formed. A large body of ground-based, rocket-borne and satellite observations demonstrates that the near-earth part of the current system consists of an intense and localised upwardly flowing field-aligned current (FAC) at the evening end of the disturbed region of the ionosphere, a more widespread, less intense downward FAC at the morning end and a westward ionospheric closure current (review by Baumjohann 1983). PiB and Pi2 are the magnetic signatures at the ground of the substorm current system.

The intense upward FAC is located at intense discrete aurora and has associated with it precipitation into the ionosphere of energetic electrons, though it is unclear if the flux of energetic electrons

accounts for all of the current (review by Kamide 1982). Fluctuations in the precipitation cause fluctuations in the auroral intensity. PiB have been seen to be closely associated with the upward FAC: they occur in the same region, start simultaneously and have the same duration. Thus the question is raised of whether the pulsations are due to the fluctuating FAC itself or the associated energetic precipitation.

A lot of work has been done in trying to explain Pi2 pulsations, since they occur globally and are a good monitor of substorm activity. The observational features of auroral Pi2, such as their morphology and the complicated way in which their sense of polarisation changes with latitude and longitude away from the source, are reasonably well known (e.g. Rostoker & Samson 1981, Pashin *et al.* 1982, Samson & Harrold 1983, Samson & Rostoker 1983). However, their generation is not well understood and there are several models contending to explain Pi2 at auroral latitudes. One example is Samson & Rostoker's (1983) model which has a complex system of field-aligned and ionospheric closure currents expanding eastward and westward to explain the observed polarisations, the ionospheric Hall current producing the D (east–west) component of the magnetic fluctuation and the FAC giving the H (north–south) fluctuation. Another recent example is Pashin *et al.*'s (1982) model where the upward FAC induces radial conductivity gradients in the ionosphere centred on the point where the FAC impinges, thus producing circular ionospheric eddy currents which generate the Pi2. Tamao (1986) and Tamao *et al.* (1985) suggest that the field of the oblique FAC may contribute a large part of the Pi2 signal at auroral and mid-latitudes. For mid-latitude Pi2 there is similar debate on the relative contributions of the far-field effects of the auroral FAC or the ionospheric eddy currents, and of the oblique FAC.

It is fairly clear that the source of at least the high frequency component of PiB, known as PiIB, is at a low altitude, below or at about 6000 km (Heacock & Hunsucker 1977, Kangas *et al.* 1979). The onsets of the energetic precipitation and the magnetic disturbance are too close to being simultaneous for the magnetic pulsations to originate in the equatorial magnetosphere, since a hydromagnetic wave generated there takes several tens of seconds to reach the ground while the energetic electrons take only a few seconds (Heacock & Hunsucker 1977, Dovbnya *et al.* 1983). During all PiB activity a disturbed E layer with enhanced conductivity is present (Heacock & Hunsucker 1981). Again an outstanding question is whether the magnetic effects arise from the FAC or from the enhanced electrojet current.

DATA

Magnetic pulsation and optical data were collected by the Antarctic Division at Macquarie Island between April and November 1986. Induction magnetometers monitored the rate of change of the three orthogonal components of the geomagnetic field. A pair of zenith-oriented photometers with a 60° field of view measured auroral emission at 427.8 nm and 557.7 nm during the night. During each night, the three magnetic and two optical signals were digitally sampled five times per second and those intervals of the digital record spanning selected events were retained after each night. The three magnetic signals were recorded continuously on chart at 30 cm/hr. A second chart recorder operated at 1 cm/min only at night to record the H and D magnetic pulsation components and the 427.8 nm trace. During that time the routine observatory instruments running at Macquarie Island included a riometer, an All Sky Camera, a three-component broadscale magnetometer and a Faraday rotation receiver measuring the total electron content of a column of the ionosphere situated between Macquarie Island and Hobart.

ANALYSIS

The 427.8 nm auroral emission follows any fluctuations in the energetic electron precipitation almost instantaneously. So, if magnetic pulsations originate in precipitation fluctuations, there should be a close correlation between the optical intensity and the magnetic fluctuations. Although similarities between the spectra of optical and magnetic fluctuations have been noted for PiB, little detailed comparison of the two has been done for PiB or Pi2. The particularly helpful features of the data collected by the Macquarie Island instruments are their high time resolution and the use of wide-angle photometers. Relatively few studies comparing optical and magnetic pulsations have been done and most of those were directed to the fairly stable PiC morning pulsations rather than the more dynamic evening PiB. Furthermore, digital sampling with good time resolution has only been employed in the most recent work (Oguti *et al.* 1984, Oguti & Hayashi 1984, Engebretson *et al.* 1983, 1986). In such correlation studies, it must be remembered that induction magnetometers sum

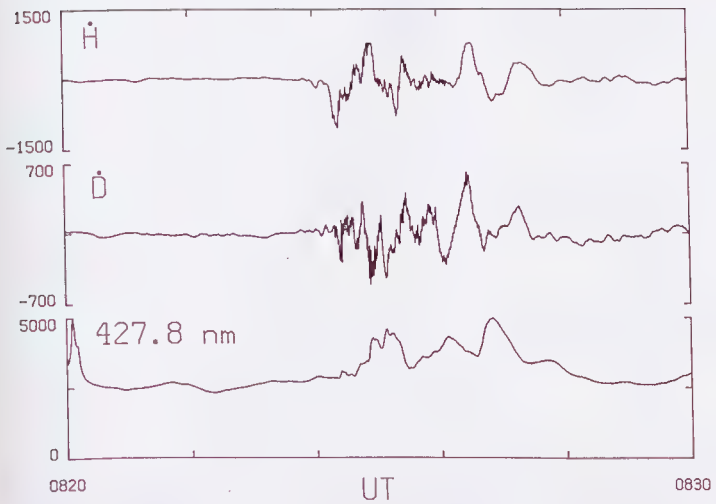

FIG. 3 — PiB with D component negatively correlated with auroral intensity (Macquarie Island, 13/9/86).

the magnetic effects of all currents within a large region. The photometers used at Macquarie Island have a 60° field of view, which is better fitted to the "field of view" of the induction magnetometers than a narrower field would be. If a correlation for PiB is found, the time delay of magnetic pulses behind the corresponding optical pulses is an important clue in deciding between candidate source mechanisms. Information about any change in a FAC is transmitted to the gound by an electromagnetic wave. Any ultralow frequency (ULF) electromagnetic wave traversing the ionosphere takes approximately two seconds to propagate through the partially ionised medium (Francis & Karplus 1960). This would result in the spreading in time of a magnetic pulse observed at the ground near the field line and due to a FAC fluctuation. At lower latitudes a two-second delay would be introduced into the magnetic effects of FACs passing overhead. On the other hand, if the magnetic pulsations are generated in the ionosphere by the mechanism that Burns & Cole (1985) and Craven & Burns (1987) postulate for PiC pulsations, then a similar difference in delays observed for the H and D pulses with respect to the optical pulses will appear and the signs of the optical–magnetic correlations are expected to behave similarly too. In fact, strong negative correlations of the optical intensity with the D component pulsations have been observed (fig. 3), as required by Burns & Cole's theory, though the peak-for-peak correlations are not as striking as is sometimes seen for PiC. The detailed shape of each of the magnetic pulses, which can only be obtained from data with a high sample rate, also helps. A fast rise and an exponential decay with the appropriate time constant, as is seen for PiC, strongly indicates an ionospheric origin.

The range of propagation of PiB and Pi2 was investigated with two statistical analyses. The events of one month were first classified as PiB or Pi2 by examination of the magnetic pulsation charts. Because the character of the event waveforms covers a continuous range from "obvious PiB" to "classic Pi2", some subjectivity entered for intermediate cases when judging if higher frequences were a significant part of the signal.

The photometer chart trace was examined for all of the PiB and Pi2 events of that month which occurred at night when the photometers were operating. It was determined which events were associated with an increase in auroral emission. Although the Macquarie Island sky is often cloudy, it is almost always possible to detect changes in auroral intensity (Burns 1983). A total of 64 PiB and 66 Pi2 occurred during the photometer operating times. Of these PiB, 46 had an associated optical increase. This indicates that if a PiB is to be detected its source must lie in a region extending not far beyond the 60° field of view of the photometer. On the other hand, of the nightime Pi2 events, only 23 had an associated auroral brightening. This lower proportion indicates that Pi2 propagate over a greater range than PiB.

Previous researchers have noted that the diurnal occurrence of PiB is peaked about local

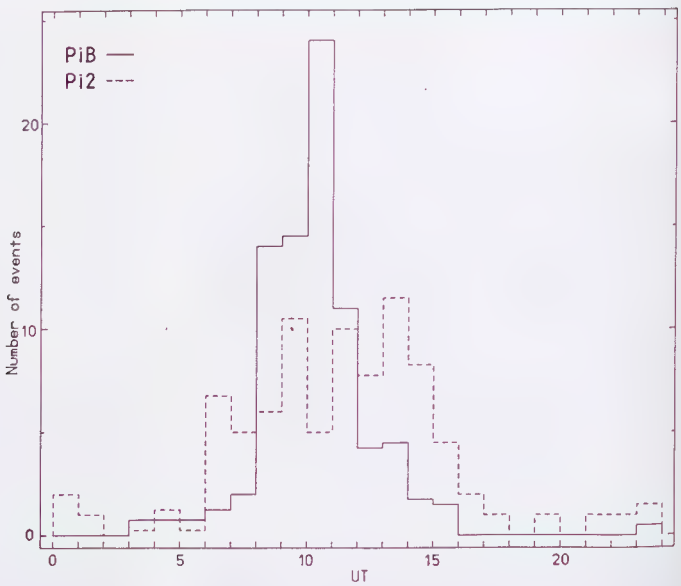

FIG. 4 — Diurnal variation of frequency of occurrence of all PiB and Pi2 events of one month (Macquarie Island, September 1986). Local magnetic midnight at Macquarie Island is at approximately 1215 UT.

magnetic midnight more sharply than that of Pi2 (review by Saito 1969). To investigate this quantitatively, the diurnal variation of the occurrence of each class was determined from the month of events examined (fig. 4). At Macquarie Island, local magnetic midnight is at approximately 1215 UT. The main Pi2 distribution clearly extends two to three hours beyond the main PiB distribution in both the morning and evening directions. We take this as evidence that Pi2 propagate longitudinally 30–40° further than do PiB. We suggest that PiB and Pi2 have the same generation mechanism at the electrojet and that the short propagation range of the higher frequencies of a PiB cause it to transform to a Pi2 as it propagates away from the source region.

Although almost equal numbers of PiB and Pi2 events occurred while the photometers were operating, only 13 PiB events occurred when the photometers were off because of daylight, whereas 27 Pi2 events occurred at such times. This fact may also be interpreted as indicating a greater propagation distance for Pi2 with respect to PiB. It is related to the occurrence distribution discussed here.

Because the source of PiB and Pi2 activity is known to be in the auroral electrojet, a study of the dependence of pulsation occurrence on the distance of Macquarie Island from the auroral oval can be expected to yield the latitudinal range of propagation of each class of pulsation. The magnetic activity index K_p gives a general indication of the position of the oval, so an analysis like figure 4 of data partitioned according to K_p would be suitable.

POTENTIAL OF FURTHER ANALYSIS

It is obvious even from the amplitude-time waveforms (fig. 5) that PiB can have several very distinct spectral components. These seem usually to have been examined separately. Either the spectrum of the high frequency component has been examined on its own and compared with those at other latitudes or with the spectra of optical measurements, or else the Pi2 component is studied on its own, the Pil being considered as noise. It may be worthwhile considering the relationship of the various components. For instance, many of the PiB waveforms recorded in this study appear to have a common development in time in several phases. Typically, for a half to one minute before the main abrupt onset there is a gradual build up at an increasing rate in the optical intensity and in one direction for the magnetic signal. If a distinct high frequency component is present, its amplitude similarly builds during this phase (see fig. 5). This phase may correspond to the pre-onset period of weak auroral activity and weak magnetic variation described by Opgenoorth *et al.*

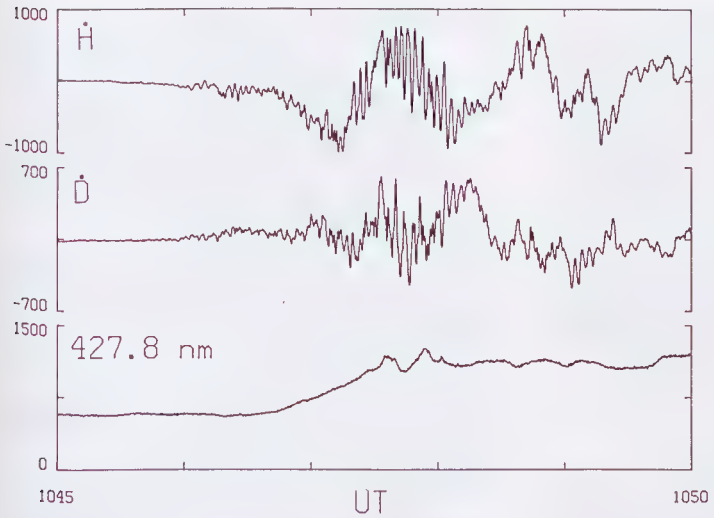

FIG. 5 — The PiB of figure 1 on an expanded time-scale to show the presence of a distinct component of period three seconds (Macquarie Island, 29/10/86).

(1980). The strong three-second period component in figure 5 is a permanent feature of PiB (Heacock 1967, Kangas *et al.* 1979). Heacock and Kangas *et al.* both postulated a cavity resonance at an altitude of a few thousand kilometres as its source. At the end of the burst, very often the Pi2 component lasts a few minutes longer than the higher frequencies. In theories which explain the Pi2 period by a hydromagnetic wave bouncing between hemispheres, the duration of the Pi2 train depends on the reflection coefficient of the ionosphere for the wave (Baumjohann & Glassmeier 1984). The duration of the higher frequency components may shed light on the mechanism of the modulation of the energetic electron precipitation, which is still unknown.

While the data at Macquarie Island were being collected, a set of induction magnetometers was run at Beveridge, Victoria. It is well known that Pi2 events can occur virtually simultaneously at auroral and mid-latitudes. Figure 6 is an example. Samson et al. (1985) described group delays of less than ten seconds. Knecht & Singer (1981) similarly report that Pi1 associated with substorm onset have an arrival-time spread of less than five seconds over a mid-latitude network spanning 15° of latitude. However, very different spectra are often noted at auroral and mid-latitudes (Fukunishi & Hirasawa 1970).

Study of the conditions under which geomagnetic pulsations in various frequency bands propagate from auroral latitudes (Macquarie Island) to mid-latitudes (Beveridge) may give information on the ionospheric ducting of magnetic disturbances. Because the ionosphere is stratified and various parameters controlling the propagation of electromagnetic and hydromagnetic waves change with altitude, waveguides result which can

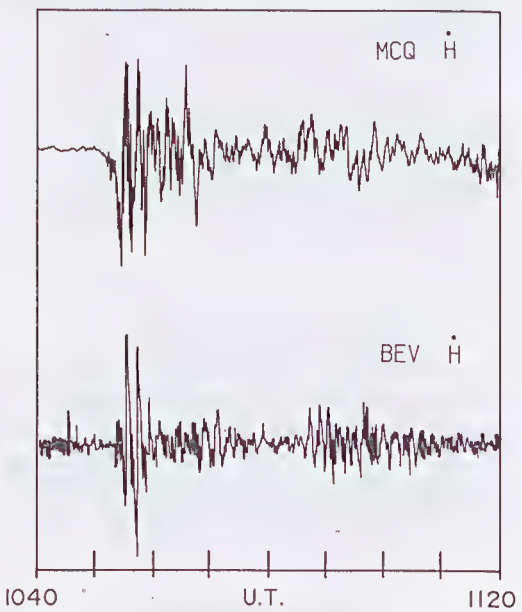

FIG. 6 — Pulsations at Beveridge coincident with a PiB event at Macquarie Island on 29 October 1986. The vertical scales are not the same and the Beveridge trace was taken from a chart record with an uncertainty in timing of up to a minute.

propagate disturbances over large distances with low loss. An example is the duct at the F_2 ionisation peak of the ionosphere, which is expected to propagate pulsations with periods of about 5 seconds or less (Manchester 1966, 1968, Greifinger & Greifinger 1968). Information on ionospheric parameters on the path from Macquarie Island to Beveridge at the times of the PiB data collection is provided by the Macquarie Island observatory instruments and the Hobart ionosonde. Accurate timing of correlated events is important in establishing if Pi2 pulsations reach mid-latitudes by the propagation of compressional hydromagnetic waves across field lines in the inner magnetosphere.

SUMMARY

We have indicated the potential of appropriate simultaneous optical and magnetic observations in the auroral zone as an aid in determining the source of those geomagnetic pulsations which are associated with the onset of auroral magnetic substorms. Preliminary results roughly quantify the ranges from which PiB and Pi2 magnetic pulsations can be detected. We propose that Pi2 pulsations may be PiB events which have had their higher frequencies removed by propagation. If confidence is gained in understanding the sources of these geomagnetic pulsations then they can be used as probes to unravel the various processes that make up an auroral substorm. The auroral substorm is an important facet of the transport of energy and particles from the sun to the earth via the magnetosphere.

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REFERENCES

AKASOFU, S.-I., 1968: *POLAR AND MAGNETOSPHERIC SUBSTORMS.* Reidel, Dordrecht.

BAUMJOHANN, W., 1983: Ionospheric and field-aligned current systems in the auroral zone: A concise review. *Adv. Space Res.*, 2: 55–62.

BAUMJOHANN, W. & GLASSMEIER, K.-H., 1984: The transient response mechanism and Pi2 pulsations at substorm onset — review and outlook. *Planet. Space Sci.*, 32: 1361–1370.

BOSINGER, T., ALANKO, K., KANGAS, J., OPGENOORTH, H. & BAUMJOHANN, W., 1981: Correlations between PiB type magnetic micropulsations, auroras and equivalent current structures during two isolated substorms. *J. Atmos. Terr. Phys.*, 43: 933–945.

BURNS, G.B., 1983: Pulsating aurora: photometer, riometer and micropulsation coil observations. Unpublished Ph.D. thesis, La Trobe University.

BURNS, G.B. & COLE, K.D., 1985: Ionospheric sources of Pi(c) pulsations. *J. Atmos. Terr. Phys.*, 47: 587–599.

CRAVEN, M. & BURNS, G.B., 1987: Pulsating aurora and magnetic Pi(c) pulsations. *ANARE Res. Notes*, 48: 17–33.

DOVBNYA, B.V., ZOTOV, O.D., POLYAKOV, A.R., POTAPOV, A.S., RUBAN, V.F. & TROITSKAYA, V.A., 1983: Possibility of ionospheric origin of some types of geomagnetic pulsations. *Geomag. Aeronom.*, 23: 215–219.

ENGEBRETSON, M.J., CAHILL, L.J., ARNOLDY, R.L., MENDE, S.B. & ROSENBERG, T.J., 1983: Correlated irregular magnetic pulsations and optical emissions observed at Siple station, Antarctica. *J. Geophys. Res.*, 88: 4841–4852.

ENGEBRETSON, M.J., CAHILL, L.J., WINNINGHAM, J.D., ROSENBERG, T.J., ARNOLDY, R.L., MAYNARD, N.C., SUGIURA, M. & DOOLITTLE, J.H., 1986: Relation between morning sector Pi1 pulsation activity and particle and field characteristics observed by the DE 2 satellite. *J. Geophys. Res.*, 91: 1535–1547.

FRANCIS, W.E. & KARPLUS, R., 1960: Hydromagnetic waves in the ionosphere. *J. Geophys. Res.*, 65: 3595–3600.

FUKUNISHI, H. & HIRASAWA, T., 1970: Progressive change in Pi 2 power spectra with the development of magnetospheric substorm. *Rep. Ionos. Space Res. Japan*, 24: 45–65.

GREIFINGER, C. & GREIFINGER, P.S., 1968: Theory of hydromagnetic propagation in the ionospheric waveguide. *J. Geophys. Res.*, 73: 7473–7490.

HALDOUPIS, C.I., NIELSEN, E., HOLTET, J.A., EGELAND, A. & CHIVERS, H.A., 1982: Radar auroral observations during a burst of irregular magnetic pulsations. *J. Geophys. Res.*, 87: 1541–1550.

HEACOCK, R.R., 1967: Two subtypes of type Pi micropulsations. *J. Geophys. Res.*, 72: 3905–3917.

HEACOCK, R.R. & HUNSUCKER, R.D., 1977: A study of concurrent magnetic field and particle precipitation pulsations, 0.005 to 0.5 Hz, recorded near College, Alaska. *J. Atmos. Terr. Phys.*, 39: 487–501.

HEACOCK, R.R. & HUNSUCKER, R.D., 1981: Type Pi 1–2 magnetic field pulsations. *Space Sci. Rev.*, 28: 191–221.

KAMIDE, Y., 1982: The relationship between field-aligned currents and the auroral electrojets: A review. *Space Sci. Rev.*, 31: 127–243.

KANGAS, J., PIKKARAINEN, T., GOLIKOV, Y., BARANSKY, L., TROITSKAYA, V.A. & STERLIKOVA, V., 1979: Bursts of irregular magnetic pulsations during the substorm. *J. Geophys.*, 46: 237–247.

KIKUCHI, T. & ARAKI, T., 1979: Horizontal transmission of the polar electric field to the equator. *J. Atmos. Terr. Phys.*, 41: 927–936.

KNECHT, D.J. & SINGER, H.J., 1981: Multistation observations of simultaneous Pi 1 and Pi 2 pulsations at substorm onsets. *EOS*, 62: 358.

McPHERRON, R.L., RUSSEL, C.T. & AUBRY, M.P., 1973: Satellite studies of magnetospheric substorms on August 15, 1968. 9. Phenomenological model for substorms. *J. Geophys. Res.*, 78: 3131–3149.

MANCHESTER, R.N., 1966: Propagation of Pc 1 micropulsations from high to low latitudes. *J. Geophys. Res.*, 71: 3749–3754.

MANCHESTER, R.N., 1968: Correlation of Pc 1 micropulsations at spaced stations. *J. Geophys. Res.*, 73: 3549–3556.

NISHIDA, A., 1978: *GEOMAGNETIC DIAGNOSIS OF THE MAGNETOSPHERE.* Springer-Verlag.

OGUTI, T. & HAYASHI, K., 1984: Multiple correlation between auroral and magnetic pulsations. 2. Determination of electric currents and electric fields around a pulsating auroral patch. *J. Geophys. Res.*, 89: 7467–7481.

OGUTI, T., MEEK, J.H. & HAYASHI, K., 1984: Multiple correlation between auroral and magnetic pulsations. *J. Geophys. Res.*, 89: 2295–2303.

OLSON, J.V. & ROSTOKER, G., 1975: Pi 2 pulsations and the auroral electrojet. *Planet. Space Sci.*, 23: 1129–1139.

OPGENOORTH, H.J., PELLINEN, R.J., MAURER, H., KUPPERS, F., HEIKKILA, W.J., KAILA, K.U. & TANSKANEN, P., 1980: Ground-based observations of an onset of localised field-aligned currents during auroral breakup around magnetic midnight. *J. Geophys.*, 48: 101–115.

PASHIN, A.B., GLASSMEIER, K.-H., BAUMJOHANN, W., RASPOPOV, O.M., YAHNIN, A.G., OPGENOORTH, H.J. & PELLINEN, R.J., 1982: Pi2 magnetic pulsations, auroral break-ups, and the substorm current wedge: A case study. *J. Geophys.*, 51: 223–233.

ROSTOKER, G., 1965: Propagation of Pi 2 micropulsations through the ionosphere. *J. Geophys. Res.*, 70: 4388–4390.

ROSTOKER, G. & SAMSON, J.C., 1981: Polarization characteristics of Pi 2 pulsations and implications for their source mechanisms: Location of source regions with respect to the auroral electrojets. *Planet. Space Sci.*, 29: 225–247.

SAITO, T., 1969: Geomagnetic pulsations. *Space Sci. Rev.*, 10: 319–412.

SAKURAI, T. & McPHERRON, R.L., 1983: Satellite observations of Pi2 activity at synchronous orbit. *J. Geophys. Res.*, 88: 7015–7027.

SAMSON, J.C. & HARROLD, B.G., 1983: Maps of the polarizations of high latitude Pi 2's. *J. Geophys. Res.*, 88: 5736–5744.

SAMSON, J.C., HARROLD, B.G. & YEUNG, K.L., 1985: Characteristic time constants and velocities of mid-latitude Pi 2's. *J. Geophys. Res.*, 90: 3448–3456.

SAMSON, J.C. & ROSTOKER, G., 1983: Polarization characteristics of Pi2 pulsations and implications for their source mechanisms, 2. Influence of the westward travelling surge. *Planet. Space Sci.*, 31: 435–458.

SOUTHWOOD, D.J. & STUART, W.F., 1979: Pulsations at the substorm onset. *In* Akasofu, S.-I. (Ed.): *DYNAMICS OF THE MAGNETOSPHERE.* Reidel: 341–355.

SUTCLIFFE, P.R., 1975: The association of harmonics in Pi2 power spectra with the plasmapause. *Planet. Space Sci.*, 23: 1581–1587.

TAMAO, T., 1986: Direct contribution of oblique field-aligned currents to ground magnetic fields. *J. Geophys. Res.*, 91: 183–189.

TAMAO, T., TANIGUCHI, H., NAMBU, M. & MIURA, A., 1985: Direct contribution of oblique field-aligned currents to magnetic field variations on the ground. *Mem. Natl Inst. Polar Res.*, Special Issue No.36: 273–280.

WILHELM, K., MUNCH, J.W. & KREMSER, G., 1977: Fluctuations of the auroral zone current system and geomagnetic pulsations. *J. Geophys. Res.*, 82: 2705–2716.

YUMOTO, K., 1986: Generation and propagation mechanisms of low-latitude magnetic pulsations — A review. *J. Geophys.*, 60: 79–105.

(accepted 15 December 1987)

A LOW-COST IONOSPHERIC DOPPLER AND PROPAGATION DELAY MONITOR

by S. Jongens and E.A. Essex

(with seven text-figures)

JONGENS, S. & ESSEX, E.A., 1988 (viii): A low-cost ionospheric Doppler and propagation delay monitor. *Pap. Proc. R. Soc. Tasm.*, 122(1): 313–318. Papers presented at the Macquarie Island Symposium, Hobart, May 1987. ISSN 0080-4703. Antarctic Division, Department of Science, Kingston, Tasmania, Australia 7150; and Physics Department, La Trobe University, Bundoora, Victoria, Australia 3083.

A monitoring system was required to study the Doppler frequency shifts and the propagation delay of modulation (so-called group delay) of the carrier frequencies for VNG, the Standard Time Frequency and Time Signal Service transmitted by Telecom Australia from Lyndhurst, Victoria (38°33′S, 145°15.7′E). The present study is a continuation of a similar monitoring of VNG on a much shorter path within Victoria. The report describes the equipment (including HF equipment and dedicated minicomputers) used in creating a monitoring system for Macquarie Island at 54°30′S, 158°57′E.

The results were in the form of chart recordings and computer-produced one-minute summaries, with the real-time recordings also made during summer on an audio tape machine for later analysis. Diurnal Doppler variations were derived from the computer data. It is demonstrated that group delay can be more accurately determined by software signal analysis than by using a hardware level discriminator.

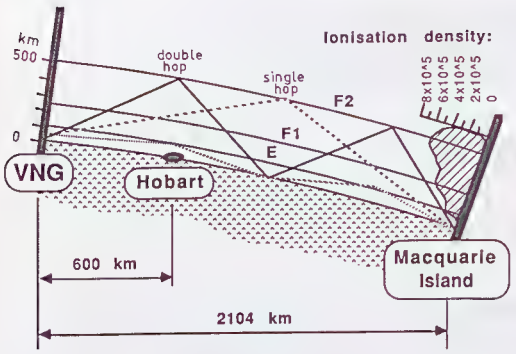
Key Words: Doppler shifts, high frequency monitoring, ionosphere, Macquarie Island.

INTRODUCTION

High frequency Doppler shifts are a significant source of interference on radio circuits propagated via the ionosphere, particularly with the more critical modulation modes, such as data circuits or medium-speed telegraph circuits. As the HF signal is refracted, the Doppler shift is introduced by the time-varying properties of the ionosphere, effectively changing the HF signal path length. This is particularly so in the higher latitudes, where the ionosphere shows rapid variations, under the influence of auroral and magnetic activities and the presence of the ionospheric trough, and radio signals are the worst disturbed. However, very little research into the ionosphere's behaviour has been done on the southern high latitude region, particularly in the Australian sector of the Antarctic and Southern Ocean region. As a forward step in the research of the near earth plasma and its effect on HF propagation, the Doppler monitoring HF receiver described here was developed. Not only can it measure very accurately the received carrier frequency of any HF transmitter (limited mainly by the accuracy of the reference oscillator available on-site), but it will also provide "clean" and useful detection of any time-signal modulation. This enables study of the variation in the propagation group delay, or the dispersion of the HF signal.

Macquarie Island is very appropriately located for this project, as other experiments and routine measurements of parameters related to the ionospheric properties are made along the same path (fig. 1). Both in Victoria (at Beveridge) and at Macquarie Island, geomagnetic pulsations are measured, and in Victoria, Hobart and on Macquarie Island, ionosondes operate routinely. A Faraday rotation experiment provides the total electron content (TEC) of the ionosphere around 48.3°S, 152.7°E (halfway between Macquarie Island and Hobart). By selecting the appropriate frequency for single hop propagation, VNG monitoring will give the ionospheric properties just north of the TEC point, completing a geographical chain of monitoring points. Other Australian National Antarctic Research Expedition (ANARE) stations will experience a much more complex signal over at least a two-hop path, with more polar absorption and much lower signal-to-noise (S/N) ratios. Macquarie Island is conveniently close to VNG, while still presenting the effects of auroral, magnetic and ionospheric events, including the winter mid-latitude trough.

VNG's transmissions on 4.5, 7.5 and 12 MHz are within one part in 10^{11} (24-hour average) of Telecom Australia's standard of frequency, which is maintained to a few parts in 10^{12} of the international definition of time interval. The ANARE



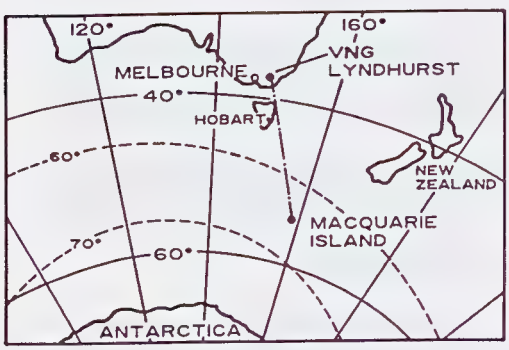


FIG. 1 — The path under study.

laboratory clocks have an accuracy of one part in 10^9. Long-term accuracy was kept within 2 ms per week. This was used for the Doppler monitor, which requires a stability of better than one part in 10^8.

METHODS

This section describes the methods followed both in hardware and software to develop a monitoring station to suit the requirements (fig. 2).

Resolution Enhancement

As the Doppler shifts are only minimal in comparison with the transmission frequencies (in the order of a few Hz over a 4.5 to 12 MHz carrier), direct measurements would be very hard to accomplish. The heterodyne principle overcomes this problem. The received frequency is mixed with the local reference, enhancing the resolution (fig. 3) (Coackley 1985).

In our application, the first heterodyne in the system is inherently designed into the HF receiver.

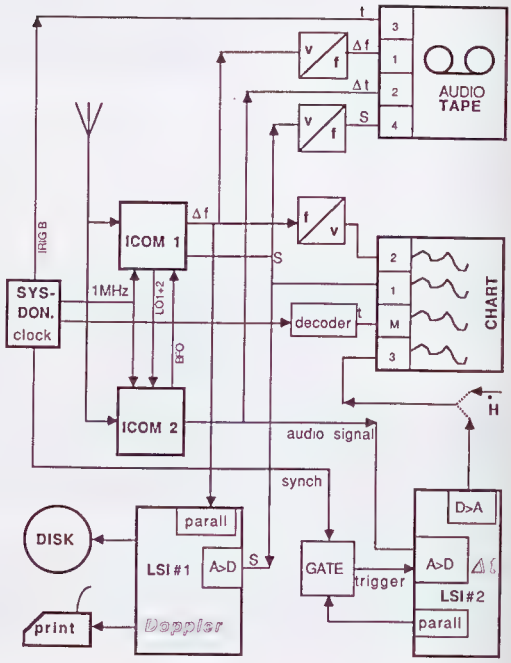


FIG. 2 — Main block diagram.

After signal amplification, the resulting frequency is then mixed again with the beat frequency oscillator (BFO), producing the Doppler frequency added to a 10 Hz offset (fig. 4).

The Receiver(s)

Reports of previous studies (Cornelius 1976) indicate that the special purpose-built receivers developed, did not necessarily provide the best results. The present report will indicate a method of using existing technology in consumer-type receivers, of very high standard but reasonably

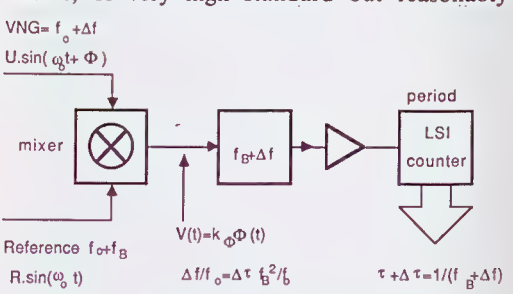


FIG. 3 — Resolution enhancement: f_B/f_0.

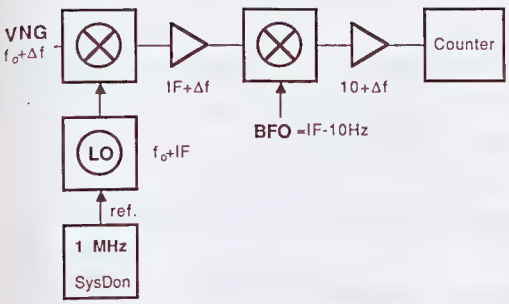


FIG. 4 — Doppler monitor principle.

priced, and modifying the receivers with minimal effort to the high-accuracy frequency requirement.

For this purpose, the receiver's local oscillators were phase-locked to the frequency standard of the laboratory clock used at ANARE's Macquarie Island station. The receiver (ICOM1), tuned to the main carrier of the transmitter station under study, was operated in CW-mode, with a BFO synthesised by a second receiver; this was given the local oscillator frequency of the first receiver, therefore effectively tuned to the same station, but operated in AM-mode, detecting one-second time marks. Only one HF frequency can be monitored at any one time. The BFO was offset to provide a beat of 10 Hz for zero Doppler shift, to remove ambiguity in the Doppler shift sign. The output of the product detector was fed into a phase-locked-loop (PLL) frequency meter and, after offsetting to bring the 10 Hz rest value to zero volts, was used as the Doppler shift value to the chart recorder (fig. 2). The time mark and signal strength traces were added to the chart, as well as a trace with the H geomagnetic pulsation channel for the observation of possible correlations.

Data Recordings

The 10 Hz-plus-shift frequency (10 Hz + Δf) was measured digitally by a standard DEC LSI-11 microcomputer, as commonly used on ANARE stations (fig. 4) and the results averaged over one-minute and again over one-hour periods. These values, the signal strength with its standard deviation values to indicate disturbances, were initially only print/plotted on paper, but were afterwards recorded on a 10 Mb hard disk to allow easier access for later study.

A second LSI microcomputer sampled the demodulation of the one-second time signal via a fast analog to digital (A/D) interface with direct memory access (DMA). A FORTRAN programme was written to deduce the average arrival time of the first few zero-crossings of the 1000 Hz time marks. However, this time value includes a demodulation phase error due to frequency-dependent refraction (i.e. dispersion) in the ionosphere. By software, it was attempted to retrace the demodulation to the supposed start of the time mark. Both results were worked out every second, and one-minute smoothed values presented to the computer VDU and recorded on chart.

It is considered more appropriate to measure time in this manner than by the more common amplitude-envelope detectors, which are more adversely affected by signal fadings and rise-time distortion, induced by narrow-band audio filters and rectifiers. Measuring the demodulation through a standard audio receiver circuit, and determining the start of the time mark retrospectively by software allows for considerably greater accuracy (fig. 5).

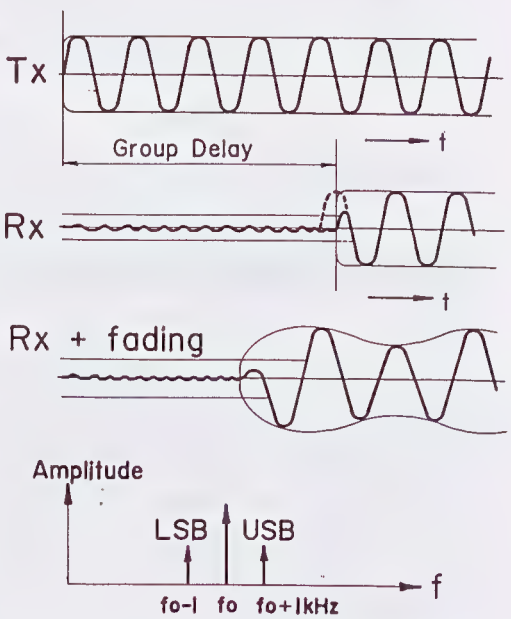


FIG. 5 — Errors in determining group delay by demodulating the time marks. The first cycle shows the phase error due to frequency dispersion of the VNG signal with sideband components. Fading aggravates the error in time detection, when using fixed threshold detectors.

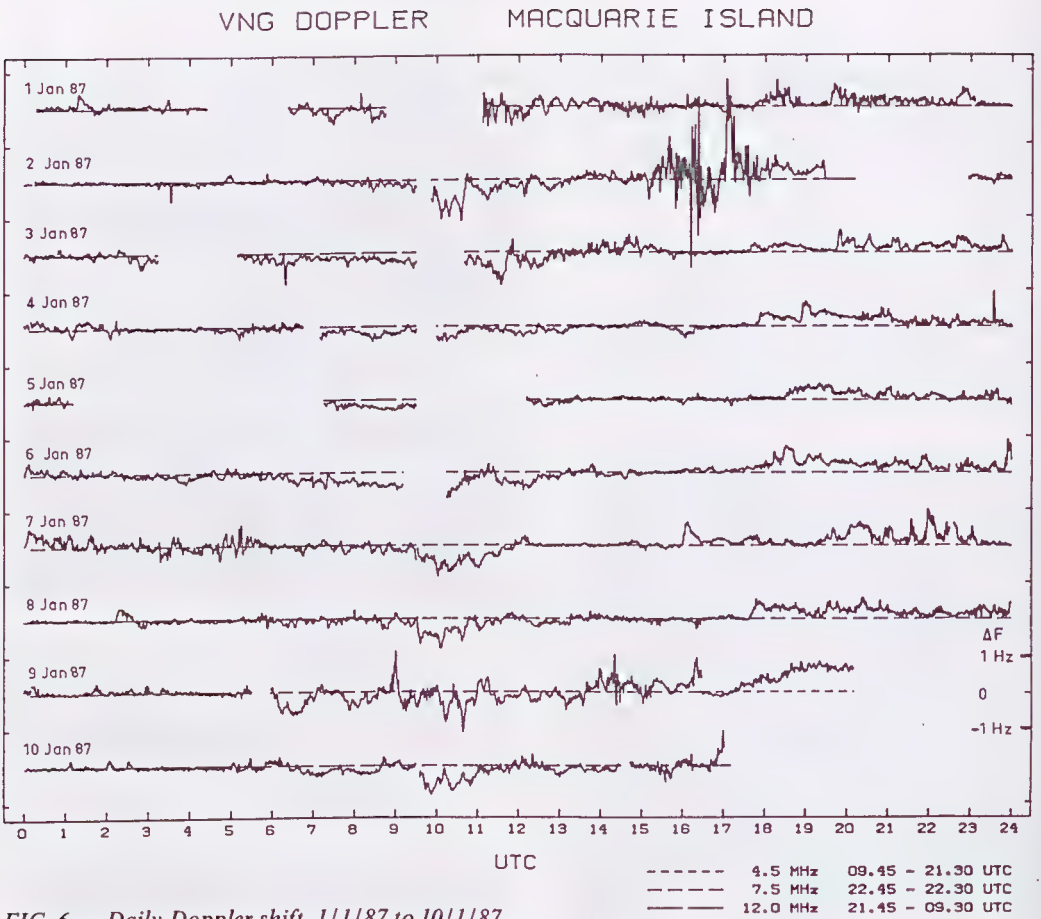


FIG. 6 — Daily Doppler shift, 1/1/87 to 10/1/87.

Aerials

With both receivers operating in the CW-mode, a comparison was made between two different receiving aerials. The aerial used under most conditions was a large "V" configuration with sides of about 150 m length, which dramatically outperformed the alternative shorter "Long Wire" aerial of about 50 m on the two lower VNG frequencies of 4.5 and 7.5 MHz. On the 12 MHz frequency the signal strengths were very similar, though not simultaneously.

SOFTWARE DEVELOPED

Doppler Measurements

A FORTRAN programme was developed to measure the variations in the carrier phase delay resulting in Doppler shifts (Δf). For every minute, and every hour, the average Δf and the average HF signal strengths, as well as their respective standard deviations, were calculated.

The output media used were printer, chart recorder and hard disk. The computed Δf value was verified against the output from the PLL frequency meter.

Path Length Measurements

In order to determine the variations of the group path delay and of the modulation delay, FORTRAN programmes were developed.

The average location of the first zero crossing, was computed by superimposing the subsequent crossings brought forward by the appropriate number of half-cycles (fig. 5). This modulation delay, determined by the zero-crossings of the demodulated time mark, differs from the group delay by a certain phase error (Φ). The 1 kHz demodulated signal "drifts" within the envelope of

the actual HF group signal; the phase error causes this 1 kHz signal to rise out of step with the commencement of the envelope. The determination of the start time of the group envelope is complicated by the noise preceding the measurement triggering point.

This phase error is mainly due to the difference between the delay the modulation encounters and that of the carrier, resulting from the frequency dispersion in the ionosphere (Toman 1967, Cornelius 1979). The modulation consists of a frequency in the upper side band (USB) of the carrier plus the modulation, f_0 + 1 kHz, and its counterpart in the lower side band (LSB), f_0 – 1 kHz (fig. 5). Even though the difference in frequency is relatively small, the ionospheric dispersion still causes them to follow different apparent paths, and the resulting phase difference is significant in terms of the phase relation between the HF carrier and the side bands.

RESULTS

Reducing the Df results over ten days into one graph (fig. 6), the regularity of the diurnal variation of the ionosphere's ionisation density and effective height is clearly recognisable. In the afternoons and evenings, the predominant Doppler shift is negative, but after sunset it runs positive again for some hours. Nighttime variations are generally negligible, but even the slightest disturbance during minor magnetic storms has a considerable effect on the Doppler shifts. An active period of geomagnetic pulsations, accompanied by a green aurora at Macquarie Island, shows up clearly on the Δf graph of the night of 2 January 1987.

Analysis is proceeding on the Δt and Φ measurements, to present them in a similar form; preliminary results are available on charts. Numerical values were displayed on the VDU screen during the software development, showing the high reliability of the procedure used to obtain the group path delay and the accompanying modulation phase shift measurement. Not many time marks were missed or rejected, as is visible on the chart traces, since every time a time mark is missed, the smoothed delay values are "held". The envelope timing (group delay) is shown every 60 time marks, equivalent to 61 seconds during good reception, as the 59th time mark every minute is not transmitted by VNG. If any time marks are missed or rejected, the group delay marks are further apart. The chart (fig. 7) shows that did not

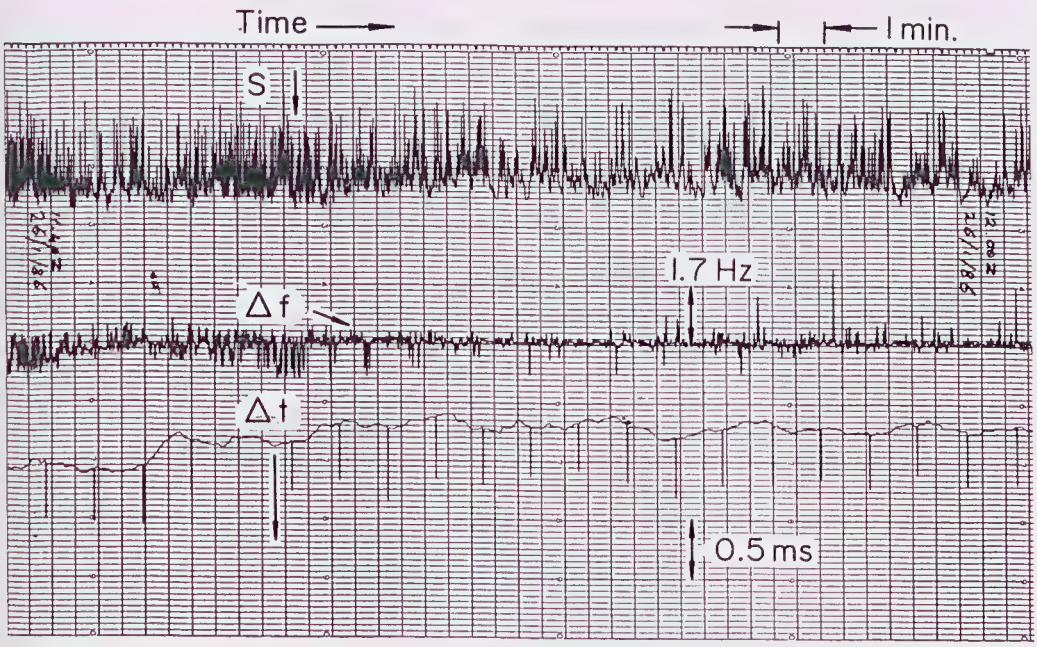


FIG. 7 — Signal strength S, Doppler shift Δf and the modulation delay Δt with the group delay every 60 time marks.

happen very often, demonstrating the success of this software approach.

FUTURE STUDIES

First steps for future studies should be the further development of software, in order to store the Δt parameters on disk. Comparison should be made between Δt of two different HF frequencies of VNG, and/or the USB versus LSB delays, using two receivers. For this purpose, a third ICOM receiver could be obtained for intercomparison of Δf for two HF carrier frequencies.

Using a later (and faster) model LSI, the two Δf and Δt measurements could be combined into one computer system, in a time-sharing mode with the Δt measurements interrupting the Δf tracing every second for a short duration. The HF receiver frequency could also be controlled at the appropriate time. The ICOM has interfacing for a digital remote control, enabling automatic HF radio frequency changes. With the improvement of the software, and the elimination of the need for a chart recorder, this would allow long periods of unattended operation.

The studies could be extended to other ANARE stations, comparing the ionospheric behaviour over different paths. The monitoring is, of course, not limited to VNG, and other stable transmitters could be considered. For instance, a dedicated ANARE transmitter, modulated with two (or more) different frequencies simultaneously, could be located in Hobart. This would allow the group delay to be determined more accurately, comparing the modulation delays of the AF frequencies. In this way, the ambiguity (when the phase-shift exceeds 2π) of the results could be eliminated. Also, it would allow closer study of non-linear frequency/delay behaviour close to the maximum usable frequency (MUF). A similar study on a shorter ionospheric hop between two points on Macquarie Island commenced during the 1987 austral winter season, comparable to previous studies in Victoria (Baulch 1982).

ACKNOWLEDGEMENTS

The writers would like to thank Dr G. Burns of ANARE for general scientific and logistic support. During the stay at Macquarie Island, the assistance of Mr I. Grant was invaluable in getting the first FORTRAN programmes off the ground. The assistance of Mr D. Barrett is gratefully acknowledged for indicating the difference between group delay and modulation delay.

REFERENCES

BAULCH, R.N.E., 1982: Studies of the Ionosphere using Oblique Incidence CW Transmission. Unpubl. Ph.D. thesis, La Trobe University, Melbourne.

COACKLEY, R., 1985: Measurements and analysis. *In* Jordan, E.C. (Ed.): *REFERENCE DATA FOR ENGINEERS.* Seventh edition. Howard W. Sams and Co. Ltd: 12–24 to 12–26.

CORNELIUS, D.W., 1976: HF Ionospheric Doppler Studies. Unpubl. Ph.D. thesis, La Trobe University, Melbourne.

CORNELIUS, D.W., 1979: Measurement of group path variations of an ionospheric propagated HF signal from its modulation envelope. *A.T.R.J.*, 13(1).

CORNELIUS, D.W. & ESSEX, E.A., 1978: HF Doppler observations of 23 October, 1976 total solar eclipse over south-eastern Australia. *J. Atmos. Terr. Phys.*, 40: 497–502.

TOMAN, K., 1967: Ionospheric phase- and group-path. *J. Atmos. Terr. Phys.*, 29: 1019–1023.

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Volume 122(2)

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ROYAL SOCIETY OF TASMANIA
ANNUAL REPORT FOR THE YEAR 1987

The Council has the honour to present to members the following report on the activities of the Society during the year.

COUNCIL AND OFFICE BEARERS

Patron
Her Majesty the Queen

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His Excellency the Governor of Tasmania
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succeeded by General Sir Phillip Bennett

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His Excellency Sir James Plimsoll, A.C., C.B.E. (1917–1987)

Sir James Plimsoll, Governor of Tasmania and President of the Society from 1982 to 1987, died on 8 May 1987.

Sir James served as President of the Society from his appointment as Governor of Tasmania in October 1982. He took a lively interest in the activities of the Society and frequently took the chair as President of the Society at meetings of the Society, both in Hobart and Launceston. He did so at the Annual General Meetings in March 1987.

The Council valued his advice on various projects in which the Society was involved and, as recently as 29 April 1987, the Senior Vice-President and Honorary Secretary had consulted Sir James.

Sir James will be greatly missed but Council are grateful for his four and a half years of dedicated service as President of the Society.

Volume 121 of the Papers and Proceedings, published in July 1987, was dedicated to the memory of this outstanding Australian.

Deaths of Members

The deaths of the following members during the year are recorded with regret: Dr G.W. Johnstone, Dr T. H.G. Dick, Mr P.B. Walker, Mr G.F. Davies, A.O., C.M.G., Mr T.D. Raphael, and Professor G.H. Newstead, O.B.E.

Honours

Two former Vice-Presidents of the Society were admitted to Membership in the Order of Australia in the 1987 Queen's Birthday Honours. They were: Dr June Olley for service to science, particularly food science (Vice-President 1972–73) and Mr J.W.C. Wyett for service to the health industry (Vice-President 1957–58).

Mr H.R. Burton of the Antarctic Division, Department of Science, was awarded the Antarctic Medal on 21 June 1987.

Royal Society of Tasmania Medal

At the 1987 Annual General Meeting it was resolved that the Royal Society of Tasmania Medal be awarded to Eric Oswald Gale Scott (1899-1986) for his distinguished research in zoology. This was the first posthumous award of the medal since its establishment in 1927.

The medal was presented to Dr D. L. Scott, Mr Scott's son, by the President, His Excellency Sir James Plimsoll, at the Annual Meeting of the Northern Branch in Launceston on 13 March 1987. Previous recipients have been:

1927	Mr L. Rodway	1970	Dr D.L. Serventy
1930	Mr C.E. Lord	1976	Dr D. Martin
1934	Mr H.H. Scott	1978	Dr M.R. Banks
1935	Dr A.N. Lewis	1982	Dr Grote Reber
1940	Dr W.L. Crowther and Prof. V.V. Hickman		

R.M. Johnston Memorial Medal

At the General Meeting in June, the R.M. Johnston Memorial Medal was presented to Dr Trevor Beard, O.B.E., in recognition of his work on hydatids in Tasmania. Previous recipients have been:

1923 Sir T.W. Edgeworth David
1925 Professor E. Wood-Jones
1929 Dr R.J. Tillyard
1934 Professor W.J. Dakin
1937 Sir David Rivett
1946 Professor L.M. Martin
1948 Prof T. Griffith-Taylor
1950 Professor J.T. Wilson
1957 Professor F. Walker
1959 Sir Edmund Hillary
1977 Professor S.W. Carey
1983 Dr A.G. Fenton

The R.M. Johnston Memorial Lecture, "Unhealthy Behaviour and the Ethics of Coercion", delivered by Dr Beard on 2 June 1987, has been published in *The Medical Journal of Australia* 142: 82–85 (18 January 1988).

Medals of the Royal Society

Mr Roger V. McNeice, Honorary Numismatist to the Tasmanian Museum and Art Gallery, has published an account of the four medals issued by the Society, entitled "Medals of the Royal Society of Tasmania" (*Journal of the Numismatic Association* 3: 27–30, 1987).

Annual Meeting

At the Annual Meeting on 3 March, Dr P.W. McCartney retired as Vice-President and Mr D. Hughes and Mr C.A.H. Payne as Members of the Council. The following were elected:

Vice-President	Mr C.A.H. Payne
Members of Council	Mr G. Davis
	Mr M.J. Walsh
	Mr P.M. Bennison (to fill casual vacancy)
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Membership

The membership is 465, an increase of 34, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	3	7
Life Members	12	35
Ordinary Members receiving Papers and Proceedings	67	291
Ordinary Members not receiving Papers and Proceedings	57	111
Associate Members	15	21
	154	465

Council Meetings

The Council met four times during the year with Mrs R. M. Cameron and Mr C. B. Tassell representing the Northern Branch on the Council.

Sir Joseph Banks Memorial Lecture

Planning is well advanced for the lecture series to be given in August–October 1988 in each Australian State capital, Canberra and London. The lecturer is Professor Sir David Smith, F.R.S., Principal and Vice-Chancellor of the University of Edinburgh, and his subject will be "Commemorating Sir Joseph Banks — symbiosis and the concept of mutual benefit".

The lecture series has been sponsored by Qantas and Ansett who are providing free travel for Sir David. The Australian Bicentennial Authority has provided a grant towards the cost of a booklet.

A medal, designed by Stephen Walker, is being struck to commemorate the lecture series.

The inaugural lecture of the series will be delivered in Hobart on 25 August 1988.

Library

Mr Stefan Petrow resumed duty as Royal Society Librarian late in 1987 after having been on leave of absence since 1984. He reports on activities at the Library for the year:

This year the library operated with reduced staff. While the day-to-day running of the library was maintained during the year, initially under the supervision of Mrs B. Chalmers and in the latter half under Mrs P. Clennett, no major projects were possible. It is hoped that users experienced little or no inconvenience.

During the year 368 members, University staff and students and other users signed the visitors' book. A number of significant and sometimes lengthy reference queries were received from members and other researchers. Many (144) volumes were borrowed and a further 135 were consulted in the library. In addition, 125 inter-library loan requests were supplied to libraries in Australia and overseas.

Binding of Royal Society serials continued during the year and 215 volumes were bound.

In September 300 copies of volume 121 of the *Papers and Proceedings* were distributed to exchange partners.

Royal Society Room

From the June meeting, the new entrance to the Tasmanian Museum and Art Gallery off Macquarie Street was used rather than that of the 1863 Henry Hunter building in Argyle Street. The entrance provides easy access for the disabled and toilets are available, including a toilet for the disabled, in the entrance building.

The Council records its appreciation to Sir Allan Knight who constructed a lectern for the room.

Publications

Volume 121 of the *Papers and Proceedings* was published on 22 July 1987. It comprised the Proceedings plus 170 pages, containing 18 papers. Thirty authors contributed papers on conchology, history, hydrology, mammalogy, palaeobotany, plant ecology, genetics, ecology and taxonomy, Quaternary history and shoreline processes.

The Tasman Peninsula Symposium proceedings are being edited and prepared for publication which is expected in the early part of the second half of the year.

By the time of the Annual Meeting it is anticipated that editorial work on the proceedings of the Macquarie Island Symposium (Volume 122, part 1) will be virtually complete and setting the volume up for printing well advanced. Publication in May is being aimed for.

Editing of Volume 122, part 2, is underway. Seven papers have been accepted and a further eight are being refereed or revised.

The Society is once more indebted to Dr Banks and Dr Smith for their dedicated work as editors.

Lectures

The following lectures were given at General Meetings during the year:

March — "Sea Level, Ice and the Greenhouse Effect" Dr P.G. Quilty, Antarctic Division, Department of Science (Vice-President)

April — "Conservation and the New Ecology" Dr Graeme Harris, CSIRO

May — "Sampling the Universe" Dr Mark Duldig, Antarctic Division, Department of Science

June — R. M. Johnston Memorial Lecture —"Unhealthy Behaviour and the Ethics of Coercion" Dr T.C. Beard, O.B.E.

July — "Malta: mid-way island" Prof. R. F. Cane

August — "Temperature and Microbiological Growth" Dr T.A. McMeekin, University of Tas.

September — "Scientific and Technological Development and the Future and the Need for Cultural Change" Ms Rhonda Galbally, Commission for the Future

October — "Hyperbaric Oxygen Therapy in Tasmania" Dr P.W. McCartney (immediate past Vice-President)

November — "The Conservation of Living Marine Resources" Dr John Gulland, Imperial College, London

Northern Branch

Chairman	Mrs R. M. Cameron
Vice-Chairman	Mr A. T. Orr
Honorary Secretary	Mr C. B. Tassell
Honorary Treasurer	Mr K. E. J. Robinson
Council Members	Dr J. C. Standard
	Mr T. W. Archer
	Mrs M. Gardner
Branch Representatives on Council of Society	Mrs R. M. Cameron
	Mr C. B. Tassell

The Branch Council met twice during the year.

The following lectures were given at General Meetings:

March — "Reactions of Tasmanian Fauna to Foreign Invasion" Dr R.G.H. Green, Queen Victoria Museum

April — "Supernovae: Past and Present" Mr M. George, Queen Victoria Museum

May — "The Moral Cycle of William Hogarth" Miss D. Dunbar, Queen Victoria Museum

June — "Unhealthy Behaviour and the Ethics of Coercion" Dr T.C. Beard, O.B.E.

July — "Australian Bicentennial Records Search" Mrs M. Morris-Nunn, Australian Bicentennial Records Search

— "Prehistoric Bones and Bunyips" Mr C.B. Tassell, Queen Victoria Museum

August — "Fossil Birds and Environmental Reconstructions" Dr R. Baird, Queen Victoria Museum

September — "Some Railway Experiences" Mr C. Smith

October — "Settlements of Aborigines" Mr N.J.B. Plomley, Queen Victoria Museum

November — "Early land settlements in Tasmania" Miss S. Morgan, Queen Victoria Museum

December — Members' Night.

Nominees to Other Bodies

The Council re-elected Mr A. R. Neilson and Dr P. G. Quilty to serve a further term on the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The 1987 State Budget provided a grant of $1 262 000 to the Tasmanian Museum and Art Gallery, an increase of 5.5% over the allocation in the 1986 Budget. About 82% of the grant has been allocated to be spent on salaries and related costs, a proportion seen by the Trustees as unhealthily high.

The Queens Warehouse, constructed in 1870 and renovated over the period 1979 to 1986, has provided improved working and storage facilities for the history and anthropology departments.

The new entrance building in Macquarie Street Hobart has provided a spacious foyer for the Museum and Art Gallery and easy access for the disabled. The entrance was opened by the Minister for the Arts, the Hon. Peter Rae, on 27 August.

The 1824 Commissariat Bond Store has been partially restored with a grant of $100 000 from the Australian Bicentennial Authority and with the support of Laver Pty Ltd.

The new building for the Tasmanian Herbarium on the University of Tasmania Sandy Bay Campus was occupied in November. The building of 570 m^2 and costing about $930 000 will be opened by the Hon. Peter Rae in February 1988. It is an innovative design, built partly underground, and will provide secure storage for the collection and pleasant working conditions for the staff.

During 1987, 107 364 people visited the Museum and Art Gallery, compared with 132 682 in 1986. In the second half of the year some of the galleries were closed in preparation for Bicentennial exhibitions.

Much work has been involved in preparation for *Tasmanian Vision*, an exhibition of the art of nineteenth-century Tasmania. The exhibition, sponsored by the SBT Bank, opened to the public on 1 January 1988 and was formally opened by the Governor-General of Australia on 14 January. The exhibition is to be shown in Hobart until 21 February 1988 and then will be on view at the Queen Victoria Museum and Art Gallery, Launceston, from 16 March until 1 May 1988. The exhibition has been indemnified by the Tasmanian and Australian Governments.

During the year there was an active programme of temporary exhibitions including: *Skinner Prout in Australia 1840-48* (December 1986–February), *Edvard Munch: Death and Desire* (February–April), *Design in Sweden Now* (April–May), *Western Australian Art* (April–May), *Moet and Chandon Touring Exhibition* (June–July), *Australian Built: Responding to the Place* (July–August), *David Chapman 1927–83: The Tasmanian Years* (July–August), *Claude Monet's "Haystack, Sun in the Haze"* (September–October), *Inuit: People of a White Land* (September–November), *Helge Larsen and Darani Lewers* (October–November), *Lloyd Rees, the Tasmanian Suite* (October–November), *Tasmanian Inventions and Innovations* (November–December), and *Captured Images: Photographs from the Collection* (December–).

A new display of medals, sponsored by the Equitable Building Society through the Art Foundation of Tasmania, was opened by H.E. General Sir Phillip Bennett, Governor of Tasmania, on 14 December. The

display includes three Victoria Crosses awarded to Tasmanians and the only George Cross awarded to a Tasmanian.

The Art Foundation of Tasmania continued to encourage support from the private sector for the Museum and Art Gallery. In addition to the medal display, the following works of art were purchased through the Foundation: *Dawn* by Arthur Fleischmann, 1963, bronze; *The Reverend Henry Dowling*, by Robert Dowling, 1850s, oil on canvas. The Friends of the Tasmanian Museum and Art Gallery Incorporated provided funds to purchase a painting *Cressy landscape with a red cloud shadow*, by David Chapman, 1982.

Dr J. E. S. Townrow was re-elected by the Council to serve a further term on the Board of Trustees of the Royal Tasmanian Botanical Gardens. She reports on the year's activities:

"Despite continued stringent cuts in Government funding, members of the staff have succeeded in maintaining the Gardens at a standard sufficient to win the Tasmanian 1987 Tourism Award for "Outstanding Achievement in the Category of Tourist Attraction", with the State's highest visitor total of over 250 000 for the year. Our Minister, the Hon. Peter Hodgman's enthusiastic support is well justified and the Superintendent, Mr Tony May, and his workers are to be congratulated.

The actual number of visitors recorded was 285 418, an increase of 21% on 1986 figures, largely attributable to the popularity of the Japanese Garden opened 18 February and publicised world wide by the wedding of famous Japanese film stars Hiroshi Fujioka and Keiko Torri.

The Government allocation for 1987/88 was $943 700, an increase of 2.3% over the 1986/87 grants, which was insufficient to cover wage and price cost variations resulting in the need to make considerable savings through cuts in services.

The Royal Tasmanian Botanical Gardens was granted registration in May as a Scientific Institution under the *Wildlife Protection (Regulation of Exports and Imports) Act* 1984, enabling import/export of native plant material to other scientific institutions.

Stage I of the Technical Support Services Centre housing the Nursery and staff, commenced December 1986, and as yet without heating, was formally opened by the Minister on 17 November. Foreman Mr Don Harding retired in March after 18 years in charge of the Nursery. It is ironic that the Nursery staff so crowded and poorly accommodated for so many years is now under strength by three due to resignations and retirement.

The popularity of the Japanese Garden was reflected in declining visitors to the Museum and Education Centre in spite of the popularity of several very fine displays. These included "Acacias", the Tasmanian Bark Artists Association exhibition of bark paintings in March, and the successful reintroduction of the live beehive in November.

The Information and Education Officer, Mr Alan Gray resigned on 30 June after nearly five years with the Gardens to take up private consulting work. The position has not yet been filled because of financial stringencies, resulting in an extra load on the office staff answering public enquiries. The Museum was reopened in August with the help of Mr Gray working on contract to set up new displays, and the volunteer Friends of the Gardens on roster duty on weekdays.

The Horticultural Therapy unit has been extended by the completion (about 12 months behind schedule) of a new outdoor practical work area with seven demonstration raised beds. Two teak tables and garden benches have been donated by the Ex-Services Womens' Association. Horticultural Therapist, Mrs Pat Mavromatis (formerly Miss Hewitt), continues to expand her services to the disabled community with classes, workshops, home and hospital visits, classes in the Women's Gaol and talks to clubs and community groups. This year the Gardens were visited by 1250 frail and elderly people thanks to the volunteer-driven bus tours run in association with the Easy Access Garden. Mrs Mavromatis has been appointed as the Deputy Chairperson of the Home and Community Care Advisory Committee.

The Gardens Plant Recording Programme has been greatly assisted by continuing mapping of the Gardens by the staff and students of the Surveying and Cartographic Department of the Hobart Technical College with the first 10 sheets of maps completed. Mrs Sue Wells, Plant Recording Officer, has recorded about two-thirds of the existing planting on the Gardens card system, and over 8000 plant labels are now placed around the Gardens. An analysis of the renowned Conifer Collection revealed nearly 500 species with representatives of all eight conifer families in the three major orders.

The Conservatory continued to delight visitors with new additions to its splendid displays including liliums and primulas. Other increasingly popular features in the year's programme were the Spring and Autumn Plant and Bird Walks followed by breakfast in the Restaurant, the Mini Tulip Festival and the Teddy Bears' Picnic.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, the University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and co-operation.

D.R. Gregg
Honorary Secretary

P.G. Quilty
Senior Vice-President

5 February 1988

THE ROYAL SOCIETY OF TASMANIA
Statement of Receipts and Payments for the year ended 31 December 1987

General Account

Balance 1 January 1987			14 767.74	Stationery	1 183.00
				Insurance	316.01
Subscriptions				Attendants' fees	821.22
253 @ $12		3 036.00		Secretarial fees	1 968.59
96 @ $ 8		768.00		Post box rental	115.00
15 @ $ 5		75.00		Postage and freight	1 771.59
2 @ $200		400.00		Photocopying	13.59
Other years		142.00	4 421.00	Subscriptions	1 575.51
				Repairs & maintenance	114.89
Interest			6 685.50	Federal & State duties	48.36
Rent			337.99	Telephone	6.66
Donations			8.00	Northern Branch	300.00
Sales of publications and				Banks Medal	524.43
Papers and Proceedings			1 330.54	Lecture expenses	450.40
Grants			4 800.00		9 209.25
Port Arthur symposium			(74.00)	*Papers & Proceedings*	7 787.00
Macquarie Is. symposium			19 500.00	Macquarie Is. symposium	3 967.50
				Investments	17 000.00
					37 963.75
				Balance 31 December 1987	13 813.02
			$51 776.77		$51 776.77

Papers and Proceedings Account

Balance 1 January 1987	2 756.23	Federal duties	0.25
Interest	606.56	Balance 31 December 1987	3 362.54
	$3 362.79		$3 362.79

Accumulation Account

Balance 1 January 1987			64 465.07
Add	Net decrease in advance subscriptions	28.00	
	Net increase in valuation of publications for sale	74.00	
	Increase in Interest Bearing Deposits	17 000.00	17 102.00
			81 567.07
Deduct	Net transfer to Trust Funds	2 494.77	
	Decreased cash at bank	37.68	2 532.45
Balance 31 December 1987			$79 034.62

ROYAL SOCIETY OF TASMANIA

Balance Sheets as at 31 December 1987

1986			*1987*
64 465.07	Accumulated Funds		79 034.62
112.00	Subscriptions in advance		84.00
	Trust Funds:		
2 285.03	— Clive Lord Memorial Fund	2 489.88	
3 831.34	— A.N. Lewis Memorial Fun	4 172.27	
1 782.47	— Morton Allport Memorial	1 944.80	
683.45	— A.A. Clark Bequest	741.79	
4 676.37	— Joseph Milligan Bequest	5 092.02	
2 543.08	— R.M. Johnston Memorial Fund	2 774.23	
1 112.40	— Henry Oliver Bequest	1 211.35	
2 547.66	— W.H. Hudspeth Memorial	2 775.44	
4 274.15	— Life Membership Fund	5 028.94	26 230.72
$88 313.02			$105 349.34
	Represented by:		
33.00	Cash on hand		33.00
	Cash at bank:		
14 767.74	— General account		13 813.02
2 756.23	— Papers & Proceedings account		3 362.54
672.17	— Clive Lord Memorial Fund		803.17
934.28	— A.N. Lewis Memorial Fund		1 114.01
860.00	Mortgage Loan		860.00
29 000.00	Commonwealth Treasury Bonds and Inscribed Stock (at cost)		29 900.00
7 000.00	Interest Bearing Deposits		24 000.00
15 000.00	Library (at valuation for insurance)		15 000.00
16 389.60	Publications (at selling prices)		16 463.60
$88 313.02			$105 349.34

The Society owns works of art which have been donated over the years and which do not appear on the Balance Sheet. They are all housed in the Tasmanian Museum and Art Gallery and are covered by that organisation's insurance. A catalogue is available to members listing these works of art.

T.A.H. Knight, Hon. Treasurer

LICHENS OF BUTTONGRASS (*GYMNOSCHOENUS*) MOORLAND IN TASMANIA

by G. Kantvilas and S. J. Jarman

(with three tables and one text-figure)

KANTVILAS G. & JARMAN, S. J., 1988 (31:x): Lichens of buttongrass (*Gymnoschoenus*) moorland in Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 1–17. ISSN 0080–4703. Tasmanian Herbarium, University of Tasmania, G.P.O. Box 252C, Hobart, Australia 7001, formerly Tasmanian Department of Lands, Parks and Wildlife (G.K.); Department of Lands, Parks and Wildlife, Macquarie Street, Hobart, Tasmania, Australia 7000, formerly Department of Botany, University of Tasmania (S.J.J.).

Eighty-nine lichen species are recorded from buttongrass (*Gymnoschoenus*) moorland in Tasmania. Of these, *Hypocenomyce australis*, *Ochrolechia frigida*, *Placynthium nigrum*, *Protoblastenia rupestris*, *Siphulastrum triste* and *Trapeliopsis colensoi* are new records for Tasmania. Over 70% of the species have Southern Hemisphere distributions, analogous to that of the majority of the vascular flora. However, 25% of the species also occur in the Northern Hemisphere, mostly in ecologically related blanket bogs or moors. A preliminary classification of lichens in twelve broad moorland vegetation types is presented. Favoured habitats for lichens include peat, rotting sedge tussocks or stumps, loose stones and large rock outcrops. Although most moorland lichen species are widespread in other Tasmanian vegetation formations, repeated, frequent fires are seen as a major threat to their long-term survival within the moorland ecosystem.

Key Words: lichens, moorland, Tasmania.

INTRODUCTION

Buttongrass moorland comprises vegetation associated with the sedge *Gymnoschoenus sphaerocephalus*, colloquially known as buttongrass. The vegetation occupies approximately 15% of the total area of Tasmania (see Duncan 1985), with its greatest representation occurring in the western half of the island (fig. 1). It is found mainly within the 1600 mm isohyet (Gellie 1980) and ranges in altitude from sea level to c. 1000 m. It also occurs in Victoria and New South Wales where it is comparatively poorly represented, both in area and diversity.

The vegetation can be divided into two basic types. The most extensive of these is found mostly in southwestern and western Tasmania. It occurs on shallow peats across hilly terrain and is analogous to the blanket bogs of the Northern Hemisphere. It also includes small acidic or alkaline outwashes on mineral soils (mainly sand) but these represent only a very small proportion of the vegetation. The second type is found in the central and northeastern highlands and in lowlands in northwestern, northeastern and southern Tasmania, with small outliers on the west coast. This vegetation is found mostly in depressions or flat areas but sometimes extends onto very gently undulating terrain. It occurs on either peaty or mineral soils, the latter including loams, sandy loams and light clays.

Buttongrass moorland consists of sedgelands, heathlands, graminoid heathlands and scrub which often form a complex mosaic, particularly in the blanket bogs. They are very inflammable and have a long history of accidental and deliberate burning. The latter has been undertaken officially for habitat management or fuel reduction near property or forests. Arson is also a cause of many fires.

Important angiosperm families present include the Cyperaceae (*Gymnoschoenus*, *Lepidosperma*, *Baumea*, *Schoenus*), Restionaceae (*Restio*, *Empodisma*, *Lepyrodia*, *Leptocarpus*), Epacridaceae (*Epacris*, *Sprengelia*), Proteaceae (*Banksia*, *Agastachys*, *Hakea*) and the Myrtaceae (*Leptospermum*, *Melaleuca*, *Baeckea*). The main pteridophytes are *Selaginella*, *Lycopodium*, *Gleichenia* and *Lindsaea*. The most common or widespread bryophytes are *Goebelobryum unguiculatum*, *Dicranoloma billardieri*, *Campylopus introflexus* and *C. kirkii*.

Lichens are often a conspicuous component of buttongrass moorland and, in some communities, may comprise the dominant ground cover. Despite this, the lichen flora has never been studied in detail, although brief, incomplete species lists are given by Bratt (1976, 1978). The present paper

FIG. 1 — The distribution of buttongrass moorland and moorland-scrub mosaic in Tasmania (after Kirkpatrick & Dickenson 1984).

reports on the lichens recorded during a general botanical survey of buttongrass moorland in Tasmania (Jarman *et al.*, in prep.) and discusses their ecology and distribution.

METHODS

The survey was limited to vegetation containing *Gymnoschoenus* (ecotones excluded), and to the small, recurring islands or strips of sedgeland, heathland and scrub which are surrounded by *Gymnoschoenus* communities and which form an integral part of the overall moorland landscape. The upper altitudinal limit of the survey was c. 1000 m, i.e. the upper limit of *Gymnoschoenus*.

The emphasis of the study was on terricolous species which comprise the main lichenological component of buttongrass moorland. Because of time constraints, studies of saxicolous species were limited to the more common, conspicuous or characteristic species. Similarly, the study of epiphytic lichens was limited to those considered characteristic of buttongrass moorland. Isolated large trees or copses occasionally serve as refugia for lichens from other vegetation formations (e.g. rainforest) but these species have not been included.

Presence/absence data for lichens were obtained from over 450 quadrats (5 x 5 m) which formed the basis of the classification of angiosperm communities (Jarman *et al.* in prep.). The quadrats were located subjectively to cover the structural, floristic, altitudinal and geographical range of the vegetation. Supplementary observations from adjacent or related vegetation provided an overview for the survey.

RESULTS

General Description

Eighty-nine lichens in 42 genera are recorded from buttongrass moorland in Tasmania. These are listed in the appendix with notes on their distribution and ecology. They include 74 macrolichens and 15 crustose species, although the latter can be expected to increase significantly with further work. Two additional, undescribed macrolichens of uncertain generic affinities were also recorded and will be treated in forthcoming papers. Two species, *Multiclavula vernalis* and *Omphalina* sp., are basidiolichens whilst the remainder are ascolichens or *lichenes imperfecti*. Several species, including *Hypocenomyce australis*, *Lithographa* sp., *Ochrolechia frigida*, *Placynthium nigrum*, *Protoblastenia rupestris*, *Siphulastrum triste* and *Trapeliopsis colensoi*, are new records for Tasmania.

Major genera with respect to diversity and/or abundance include *Cladonia* (23 species), *Cladia* (7 species) and *Siphula* (4 species), and together these comprise the core of the lichen flora. *Xanthoparmelia* (8 species) is dominant on many large rock outcrops. Additional common genera include *Hypogymnia*, *Lecidea* s.lat. and *Menegazzia* (on rocks or epiphytic), *Cladina* (on soil) and *Umbilicaria* (on rocks).

A few species, e.g. *Cladia inflata*, *C. moniliformis*, *Micarea* sp., *Multiclavula vernalis*, *Pycnothelia caliginosa* and *Siphula jamesii* are mainly confined to buttongrass moorland but most others are widespread outside of this vegetation.

The low proportion of lichens peculiar to buttongrass moorland may be attributed in part to the character of the vegetation, in so far as it often forms a mosaic with other formations such as sclerophyll forest, rainforest and alpine vegetation. The close proximity of these formations enables many of the ecologically wide-ranging lichens to spread into buttongrass moorland.

Within the moorland, the majority of lichens present are restricted to specialised niches or communities and their distribution patterns are consistent with their range in other vegetation types. For example, species from heathlands are mostly confined to shrubby moorland communities whilst species from alpine vegetation are found mostly in high altitude moorland. Only very few lichens, e.g. *Cladia aggregata* and *Cladonia southlandica*, are widespread across a broad range of the vegetation.

More than half (55%) of the species recorded are terricolous. Peat is the most common substrate available and supports species usually found on mineral soil, e.g. *Cladonia corniculata*, as well as those characteristic of rotting wood or litter, e.g. *C. weymouthii* and *C. subdigitata*. Most peats and soils in buttongrass moorland have a pH = 4–4.5 (Tarvydas 1978, unpubl. data). However, some communities, particularly in southwestern Tasmania, contain open sandy or silty outwashes or pans where the pH can be as high as 9 and there is a concomitant change in the vascular flora (Brown *et al.* 1982). Terricolous lichens are absent from such sites although this could be due to factors other than pH. The pans are often poorly drained, periodically inundated and their fine sand or silt is not colonised by lichens even where the pH is low. Very depauperate lichen thalli are usually present at the margins of the pans on mounds of peat.

Well-drained, well-lit habitats are most favourable for lichen growth in buttongrass moorland. Rotting *Gymnoschoenus* hummocks provide an ideal substrate above the matrix of sedges and shrubs but gaps between hummocks are also colonised. The most common lichens include *Cladia aggregata*, *C. inflata*, *C. retipora*, *C. sullivanii*, *Siphula decumbens*, *Cladonia southlandica* and *C. subsubulata*, the last two species often occurring only as mats of squamules. All these species generally become depauperate in very moist, shaded sites which tend to be favoured by bryophytes. However, some lichens do occur in well-lit, boggy sites and these include *Siphula jamesii*, *Multiclavula vernalis* and the grotesquely inflated species, *Cladia moniliformis*. At high altitudes, *Siphula complanata* and *S. fragilis* are locally abundant in and around shallow, muddy puddles.

Lichens increase in diversity in some of the more shrubby buttongrass communities where the peat is more fibrous and better drained. *Cladonia* in particular becomes abundant, with additional species such as *C. campbelliana*, *C. capitellata*, *C. cervicornis* spp. *verticillata*, *C. corniculata*, *C. praetermissa*, *C. pyxidata*, *C. subdigitata* and *C. weymouthii* locally common. *Knightiella splachnirima*, *Trapeliopsis colensoi* and *Cladina confusa* also occur primarily in such vegetation. Some communities commonly include open areas between shrubs and sedge hummocks where lichens form a diverse, extensive mat, interspersed with low angiosperms such as *Hibbertia procumbens* and *Schoenus tenuissimus*.

As the moorlands age, several communities, particularly those with a significant shrub component, ultimately produce a closed canopy of woody species. In many cases, the lichens are affected adversely, in a manner similar to that described by Gimingham (1960) for *Calluna* heaths in the Northern Hemisphere where lichens are eliminated as the shrubbery grows denser. However, in other situations, lichens remain well represented in the vegetation and may even increase in biomass and diversity (cf. Coppins & Shimwell (1971) on British heathlands). Most shrubs in Tasmanian moorland have fine foliage which allows light to filter through to the ground. This light is apparently insufficient to maintain a vigorous ground layer of angiosperms and in some sites, canopy closure of the dominant species (e.g. *Leptospermum* or *Melaleuca* spp.) has all but eliminated *Gymnochoenus* and other sedges. The resulting ground layer is dominated instead by mosses (e.g. *Ptychomnion aciculare*) and lichens which include typical moorland species as well as some more characteristic of open forest, e.g. *Cladonia gracilis* ssp. *tenerrima*, *C. ochrochlora*, *C. scabriuscula* and *Peltigera dolichorhiza*. In some very old communities (to c. 70 years), canopy closure does not occur and a pattern of large, widely-spaced shrubs and sedges is maintained, interspersed with mats of Cladonia and Cladia species. In such cases, the lichens may be inhibiting the establishment of angiosperm species; evidence for such an effect has been presented from Northern Hemisphere heathlands by Hobbs (1985).

On steep slopes, mostly in southwestern Tasmania, extensive areas of gravel and small stones are exposed where the peat surface has been largely removed by erosion or fire. Terricolous lichens become very restricted although *Micarea*

sp. is locally abundant and serves to stabilise the remnants of peat. The gravel supports several inconspicuous crustose lichens, e.g. *Lithographa* sp. and species of Lecideaceae s.lat., particularly *Lecidea leptocarpa* aggr.

Large rock outcrops are a common feature of the buttongrass moorland landscape, particularly in western Tasmania. They act as islands of diversity in an otherwise lichenologically rather depauperate vegetation by providing a wide range of microhabitats as well as some degree of fire-protection. Several rock types are represented including conglomerate, dolerite, basalt, granite, limestone and Precambrian metamorphic rocks. The last type tends to support the most diverse lichen flora. Limestone has a particularly depauperate but very characteristic lichen flora which includes *Placynthium nigrum*, *Protoblastenia rupestris* and several as yet unidentified species of *Lecideaceae* s.lat. Dominant species on rock outcrops include species of *Parmeliaceae*, e.g. *Parmelia signifera*, *Flavoparmelia haysomii*, *Hypotrachyna sinuosa* and *Xanthoparmelia* spp., of which *X. mougeotina* is the most common and widespread. Other common species include *Rhizocarpon* cf. *geographicum*, *Lecidea coromandelica* and *Protoparmelia petraeoides*. Apices of the rocks are often crowned with tufts of *Usnea torulosa* whilst *Cystocoleus niger* colonises the sheltered sides. Rock outcrops in coastal or lowland areas may support species of *Heterodermia*. At high altitudes, additional lichens such as *Neofuscelia stygioides*, *Parmelia signifera*, *Menegazzia aeneofusca* and *Umbilicaria* spp. are also present, but these may range to sea level on Precambrian rocks in southwestern Tasmania. Several typical rainforest epiphytes also occur on the outcrops and may represent relics from a time when rainforest was more extensive over the present-day range of buttongrass moorland. Examples include *Sphaerophorus tener*, *S. melanocarpus* and *Megalospora lopadioides*, as well as the vascular species, *Apteropteris applanata*, *Hymenophyllum* spp. and *Prionotes cerinthoides*.

Peat-filled crevices in the rock outcrops commonly abound with lichens, including *Cladia* spp., *Siphula decumbens* and several *Cladonia* spp., e.g. *C. capitellata*, *C. chlorophaea* and *C. pleurota*. Less widespread species include *Gymnoderma melacarpum*, *Ochrolechia frigida* and *Wawea fruticulosa*. The outcrops are usually surrounded by vegetation more shrubby than the local moorland and hence there also tends to be a greater diversity of terricolous species in the general vicinity of these rocks.

Epiphytic species are poorly developed in buttongrass moorland, mainly due to a paucity of substrates since the shrubs present rarely attain sufficient size or age to support diverse assemblages of epiphytes. *Lecidea laeta* is common on the twigs of myrtaceous shrubs whilst *Usnea arida*, *Lecidella elaeochroma*, *Menegazzia platytrema*, *Hypogymnia turgidula* and *Hypotrachyna sinuosa* are common on emergent trees or large shrubs of *Banksia*, *Hakea* or *Casuarina*. Dense, very wet copses of *Melaleuca* often support *Wawea fruticulosa*. *Catillaria* sp. is common on decorticated trunks of *Eucalyptus* whilst rotting stumps and logs are colonised by *Cladia schizopora*, *Cladonia squamosula* and *C. subdigitata*. Charred wood supports *Hypocenomyce australis* and, in low rainfall areas, *Thysanothecium scutellatum*. Some shrubby buttongrass moorland communities are precursors in the succession to scrub and forest (Jackson 1968) and hence may ultimately develop diverse epiphytic floras, more akin to sclerophyll forest or rainforest (see Kantvilas et al. 1985).

Irrespective of species abundance, the lichen flora of buttongrass moorland is generally very depauperate in comparison with that of other Tasmanian vegetation. Few of the sample sites contained more than 5-6 species and although more than 80 lichens were recorded overall, many of these represent incidental occurrences of species which attain their peak development elsewhere. Even the characteristic moorland species such as *Siphula decumbens*, *Cladia aggregata*, *C. retipora*, *C. sullivanii* and the *Cladonia* species are widespread in other vegetation types. The overall low number of species in buttongrass moorland suggests that lichens have been unable to exploit the particular conditions prevailing there and hence the flora is comprised essentially of wide-ranging opportunistic species.

Distribution

The majority of lichens in buttongrass moorland are widespread in Tasmania and many apparent regional differences (table 1) disappear when occurrences of the lichens in other vegetation types are considered. However, within the moorland lichen flora, there is a marked difference between southwestern Tasmania and the remainder of the island. This difference is also evident in the vascular flora. Lichens mostly confined to southwestern Tasmania include *Multiclavula vernalis*, *Pycnothelia caliginosa*, *Lithographa* sp., *Cystocoleus niger*, *Micarea* sp., *Pertusaria* sp.,

TABLE 1
Frequency of Terricolous Lichens in 12 Classes of Buttongrass Moorland Vegetation*

Species groups	Species	Vegetation groups**											
		1	2	3	4	5	6	7	8	9	10	11	12
1	*Cladia aggregata*	o	o	*	x	x	x	x	x	‡	x	o	+
	Cladonia southlandica	+	o	+	‡	o	‡	‡	x	-	‡	o	-
	Cladia retipora	-	o	-	‡	‡	x	‡	‡	+	o	+	-
	Cladonia subsubulata	-	-	-	+	o	o	‡	o	-	o	+	-
	Cladina confusa	-	-	-	+	+	o	o	+	-	-	-	-
	Cladonia capitellata	-	-	-	-	+	o	o	o	o	o	-	-
2	*Siphula jamesii*	-	-	+	o	o	-	-	-	-	-	-	-
	Micarea sp.	-	-	-	o	o	-	-	-	-	-	-	-
	Multiclavula vernalis	+	+	+	-	+	-	-	-	-	-	-	-
	Cladia moniliformis	o	o	‡	x	x	-	-	-	-	+	-	-
3	*Cladia fulignosa*	-	-	-	-	+	-	-	-	-	-	-	-
	Pertusaria sp.	-	-	-	-	o	-	-	-	-	-	-	-
	Cladina mitis	-	-	-	-	+	-	-	-	-	-	-	-
	Wawea fruticulosa	-	-	-	-	+	+	-	-	-	-	-	-
	Pycnothelia caliginosa	-	-	-	-	+	-	-	-	-	-	-	-
4	*Siphula decumbens*	-	-	o	x	x	‡	o	-	-	-	-	-
	Cladonia murrayi	-	-	-	+	o	o	o	-	-	-	-	-
	Cladia sullivani	-	+	-	o	‡	‡	‡	o	-	-	-	-
	Siphula fragilis	-	-	-	+	o	-	o	-	-	-	-	-
5	*Cladonia weymouthii*	-	-	-	-	-	o	+	+	+	-	-	-
	Cladonia subdigitata	-	-	-	-	-	o	o	+	+	-	-	-
	Cladonia ochrochlora	-	-	-	-	-	o	-	+	o	-	-	-
	Cladonia cervicornis subsp. *verticillata*	-	-	-	-	-	+	o	o	o	-	-	-
	Cladonia corniculata	-	-	-	-	-	-	o	o	o	o	-	-
	Cladonia gracilis subsp. *tenerrima*	-	-	-	-	-	+	-	+	o	-	-	-
	Cladonia pleurota	-	-	-	-	-	+	o	+	-	-	-	-
	Cladonia squamosula	-	-	-	-	-	o	o	o	-	-	-	-
	Cladonia ramulosa	-	-	-	-	-	+	-	o	-	-	-	-
	Knightiella splachnirima	-	-	-	-	-	o	o	o	-	-	-	-
	Cladia schizopora	-	-	-	-	-	+	-	o	-	-	-	-
6	*Omphalina* sp.	-	-	-	-	-	-	o	-	o	-	-	-
	Trapeliopsis colensoi	-	-	-	-	-	-	o	-	o	-	-	-
	Cladonia pyxidata	-	-	-	-	-	-	o	-	o	-	-	-
	Cladonia tessellata	-	-	-	-	-	-	o	-	-	-	-	-
	Siphula complanata	-	-	-	-	-	-	o	-	-	-	-	-
7	*Cladonia campbelliana*	-	-	-	-	-	-	o	o	-	-	-	-
	Cladonia wilsonii	-	-	-	-	-	-	+	+	-	-	-	-
	Cladonia chlorophaea	-	-	-	-	-	-	o	+	-	-	-	-
	Cladonia praetermissa	-	-	-	-	-	-	-	o	-	-	-	-
	Cladonia angustata	-	-	-	-	-	-	-	+	-	-	-	-
Number of sites		25	40	12	50	40	20	10	33	10	8	55	5

* Descriptions of vegetation and species groups are given in tables 2 and 3 respectively.

** x denotes frequency >80%, ‡ 50-80%, o 10-15%, + <10%.

Siphula jamesii and *Cladia moniliformis*. Lichens occurring mostly outside the southwest include *Thysanothecium scutellatum*, *Cladonia angustata* and *C. praetermissa*, but these are essentially dry sclerophyll forest species occurring opportunistically in moorland. Some lichens show regional distributions in the lowlands but become ubiquitous at higher altitudes (above c. 750 m). For example, in the lowlands, *Siphula decumbens* is a characteristic southwestern species and *Cladonia subsubulata* is characteristic of non-southwestern communities but, at high altitude, both are widespread throughout Tasmania.

Several species are confined to high altitudes and their occurrence in buttongrass moorland usually represents the lowest limits of their range, e.g. *Cladia fuliginosa*, *Cladina mitis*, *Siphula fragilis*, *S. complanata*, *Siphulastrum triste* and *Ochrolechia frigida*. However, altitudinal distinctions become blurred in the southwest where many high altitude lichens, particularly saxicolous species such as *Umbilicaria* spp. and *Neofuscelia stygioides*, extend to sea level. Several alpine angiosperms exhibit a similar distribution pattern. This effect of depressed altitude further contributes to the distinctiveness of the flora of southwestern Tasmania.

In addition to changes in composition, the lichen flora tends to increase in biomass at high altitude with *Cladia sullivanii*, *C. retipora*, *Cladonia capitellata* and *Cladina confusa* becoming particularly well developed. Other species, e.g. *Cladonia campbelliana*, *C. pleurota*, *C. pyxidata*, *C. subdigitata*, *C. tessellata*, *C. weymouthii* and *Menegazzia aeneofusca*, also become more common, However, our observations indicate that these species are capable of proliferating at all altitudes. Their comparatively poor development and scarcity in the lowlands may be due at least partly to fire history. In general, the lowland moorlands have been burnt more frequently than highland moorlands, resulting in the virtual elimination of much of their lichen flora.

Relationships with Higher Plant Floristics

The relationships between 12 vascular plant groups in buttongrass moorland and their constituent lichens are summarised in table 1. These groups, described briefly in table 2, are based on the communities described by Jarman *et al.* (in prep.) but several related communities with similar floristic, geographical, altitudinal or structural characteristics have been combined. Two of the groups (numbers 9 and 12 in table 2), representing *Sphagnum* bogs and high altitude grasslands respectively, are not strictly buttongrass moorland vegetation but often contain *Gymnoschoenus* at their boundaries. Lichen species have been classified into seven groups which are described in table 3. Only terricolous species (or those on the ground on rotting wood etc.) are included. Saxicolous and epiphytic lichens are omitted because their occurrence depends on the presence of large rocks or trees rather than directly on the nature of the host vegetation. The data presented in table 1 relate specifically to the occurrence of lichens in buttongrass moorland and apparent patterns may alter if distributions in other vegetation types are considered.

The results from table 1 support many of the geographical, altitudinal and ecological trends already discussed. For example, the floristic distinctions between buttongrass moorland in southwestern Tasmania (groups 1–6) and elsewhere (groups 7–12) are clearly evident, with lichens from species groups 2–4 characterising the former. However, there is a similarity between southwestern shrubby copses (group 6) and heathlands elsewhere in Tasmania (groups 7–8) as exemplified by the lichens in species group 5. These vegetation groups (numbers 6–8) also have many vascular plants in common. The substantially greater diversity of lichens in well-drained, shrubby communities (vegetation groups 4–8) in comparison with dense sedgy or very wet communities (1–3, 10–11) is also well illustrated, with all but a few lichens from species group 1 (the ubiquitous species) being confined to the former. Lichens are particularly depauperate in high altitude grassland (group 12) where the dense ground layer of herbs excludes their colonisation. They are also relatively impoverished in *Sphagnum* bogs where they are unable to colonise actively growing *Sphagnum* mounds (cf. Foster 1984, for raised bogs in Canada). However, lichens may develop locally on dead or fire-scorched *Sphagnum* or rotting wood. Emergent *Richea* spp. in this community support a diverse epiphytic flora of essentially rainforest species.

Effects of Fire

The majority of lichens from buttongrass moorland are very sensitive to fire and are easily destroyed. Not only are the species killed outright but their habitat, especially the peat substrate, can

be severely damaged. Thus repeated occurrence of fire at short intervals can be expected to result in a marked loss of diversity, reducing the flora to a few, ubiquitous, rapidly colonising species. The most fire-tolerant lichens appear to be *Cladonia southlandica*, *Cladia aggregata*, *C. inflata* and, to a lesser extent *Cladonia subsubulata* and *Siphula decumbens*. Instances where depauperate thalli of these species have re-established (in the case of *Cladonia* as basal squamules only) c. 2-5 years after a fire have been observed. However, it is difficult to imagine how thalli of this type could survive repeated burning at short intervals. Thus with high fire frequencies the long-term survival of even the most fire-tolerant species is doubtful. On a very local scale in some very dense communities, occasional fires may aid the establishment of lichens by opening up the vegetation, a situation akin to that described for *Calluna* heaths by Gimingham (1978) and Hobbs (1985).

In addition to fire frequency, lichen recovery seems dependent on the intensity of the fire. For example, scorched *Cladonia* squamules often remain after a fire although it is not clear to what extent they are still viable. It is also possible that the underground rhizines of *Siphula* could survive fire provided the peat is only scorched at the surface rather than stripped of its uppermost layers. Recovery may also depend on "site quality". Observations from adjacent sites in buttongrass moorland which have been burnt simultaneously indicate that lichens as well as most shrub species tend to re-establish sooner and grow faster in heathlands or copses than in graminoid communities.

Large rock outcrops in buttongrass moorland can provide some protection from fire and serve as sources of recolonisation. However, repeated burning of an area increases the chances of ultimately eliminating even these refugia. Saxicolous species on exposed surfaces are easily lost and are slow to recover on scorched rock, whilst burning and erosion of peat in crevices leads to a loss of terricolous species through the destruction of their habitat.

The long-term result of fire in Tasmania's buttongrass moorland is difficult to predict. On the one hand, lichens are clearly very fire-sensitive. On the other, they have managed to survive in buttongrass moorland up to the present time despite the fact that fire has been a repeated occurrence in the vegetation throughout its history. Given the present policy in Tasmania of frequent fuel reduction burning, it seems inevitable that in some areas, lichens will become locally extinct because their recolonisation after one fire will scarcely have begun before another fire destroys their new growth. This situation is analogous to that described for British moors which are burnt regularly for grouse and sheep management and where most lichens have been eliminated (Gilbert 1980a, b, Hawksworth 1969). In order to avoid large-scale extinction in Tasmania, it seems of critical importance to preserve a diversity of vegetation ages and types so that some refugia for lichens will always be maintained.

Phytogeography

Over 70% of the lichens recorded from buttongrass moorland have predominantly Southern Hemisphere distributions, similar to the distributions of much of the vascular flora (e.g. the Restionaceae, Proteaceae and Epacridaceae). Approximately one-third of these lichens comprise genera and species confined to or centred in the far south of the Southern Hemisphere (Tasmania, New Zealand, southern South America) and can be referred to as "austral cool temperate" (after Jørgensen 1983). Examples (include the genera *Siphula*, *Knightiella*, *Menegezzia*, *Placopsis* and *Siphulastrum*, as well as the species *Cladonia murrayi*, *C. corniculata*, *Hypogymnia lugubris*, *Neofuscelia stygioides*, *Trapeliopsis colensoi* and *Wawea fruticulosa*. The remainder have more "warm temperate" (Jørgensen 1983) or "Australian" (after Galloway 1979) distributions, e.g. *Cladia*, *Thysanothecium*, *Xanthoparmelia*, *Cladonia augustata*, *C. capitellata*, *C. kuringaiensis*, *C. southlandica*, *Hypocenomyce australis*, *Protoparmelia petraeoides*, *Parmelia signifera* and *Usnea torulosa*. The large endemic element in the vascular flora (c. 30%) is not evident in the lichens, with only *Siphula jamesii*, *Cladia moniliformis* and *Micarea* sp. being endemic to Tasmania. However, additional endemics are likely to be found amongst the undescribed taxa.

Despite this essentially "southern" nature of the lichen flora, there are many similarities between Tasmanian buttongrass moorland and analogous blanket bogs and moors in the Northern Hemisphere, particularly Britain. For example, the generic composition of the two lichen floras is similar, with *Cladonia* and *Cladina* constituting a major component of both (see Gilbert (1974), Watson (1932) for data on Britain). Similarly species of *Lecidea* s. lat. comprise much of the flora on small stones whilst *Parmelia* s.lat.,

TABLE 2
Description of Vegetation Groups (after Jarman *et al.* in prep.)

Group number	Distribution	Remarks
1	Lowland, mostly SW Tas, also in NW	Open sandy or silty outwashes, including alkaline pans. Angiosperms sparse, stunted. Common species include *Actinotus suffocata*, *Baumea* spp., *Drosera arcturi* and *D. spathulata* (in NW). *Gymnoschoenus* depauperate. Mosses (*Dicranoloma billardieri*) often dominant. Lichens rare or absent, confined to bases of shrubs.
2	Lowland, throughout Tas	Usually flat, poorly drained sites on peat. Low density of angiosperms, including *Leptocarpus tenax*, *Lepyrodia tasmanica* and *Microlaena tasmanica*. *Gymnoschoenus* in large hummocks, forming a dense ± pure stand, sometimes with emergent shrubs. Lichens rare, ± confined to rotting hummocks.
3	Lowland, SW Tas	Very wet, poorly drained facies of Group 4. Angiosperms diverse, mostly as in Group 4 but *Winifredia sola*, *Oschatzia saxifraga* and *Baumea tetragona* often present. *Gymnoschoenus* common, in tufts. Lichens uncommon, mostly around shrub bases.
4	Lowland SW, rare in NW	Most common and widespread vegetation type in SW Tas, occurring on peat. Angiosperms diverse, include *Leptospermum nitidum*, *Melaleuca squamea*, *Baeckea leptocaulis*, *Boronia pilosa*, *Epacris corymbiflora*, *Restio mono cephalus* and *Actinotus bellidioides*. *Gymnoschoenus* common. Lichens common in clearings. Additional species present on small, loose stones.
5	High altitude SW Tas	Often dense, shrubby or sedgy communities on peat. Angiosperms include *Epacris heteronema*, *Isophysis tasmanica*, *Dracophyllum milliganii* and *Eucalyptus vernicosa*.*Gymnoschoenus* usually in large hummocks. Lichens locally abundant on rotting hummocks or in small, stony clearings where *Donatia novae-zelandiae*, *Oreobolus* spp., *Lepidosperma inops* and *Pentachondra pumila* occur.
6	Lowland, SW Tas	Heathlands or copses on well-drained peaty soil. Common angiosperms include *Eucalyptus nitida*, *Leptospermum scoparium*, *Dillwynia glaberrima*, *Boronia citriodora* and *Monotoca submutica*. *Gymnoschoenus* absent or poorly developed, often dying. Lichens common in small clearings, particularly where wombats (*Vombatus ursinus*) graze, on rotting stumps or decaying hummocks. Similar copses dominated by *Melaleuca squarrosa* occur in wet, poorly drained sites but are depauperate lichenologically.
7	High altitude, outside SW, mainly on Central Plateau	Heathland communities with many angiosperms, including *Hibbertia procumbens*, *Tetratheca procumbens*, *Coprosma moorei*, *Poa gunnii*, *Pentachondra pumila* and *Leucopogon* sp. *Gymnoschoenus* uncommon, in sparse tufts. Lichens on peat, usually common, especially in clearings between shrubs.
8	Lowland, outside SW Tas	Shrubby communities, mostly on well-drained slopes. Common angiosperms include *Leptospermum scoparium*, *Epacris impressa*, *Aotus ericoides*, *Hibbertia procumbens*, *Dillwynia glaberrima* and *Leucopogon collinus*. *Gymnoschoenus* uncommon. Lichens usually abundant, especially on peat in clearings between shrubs.
9	High altitude, Central Plateau	Bogs dominated by *Sphagnum* sp. Common angiosperms include *Restio australis*, *Carex* spp., *Empodisma minus* with emergent *Rich gunnii* and *R. scoparia*.*Gymnoschoenus* rare, in large hummocks, mainly at edges of bog or in disturbed sites. Lichens poorly developed, localised.

Group number	Distribution	Remarks
10	High altitude, Central Plateau and NE Highlands	Sedgy communities, probably derived from raised bogs (type 9) which have been degraded by frequent burning. Common angiosperms include *Restio australis*, *Diplarrena latifolia*, *Lepyrodia tasmanica* and *Xyris* spp. *Gymnoschoenus* common, in crowded hummocks. Lichens local in clearings between sedges or on dead hummocks.
11	Lowland, outside SW Tas	Sedgy, poorly drained communities. Common angiosperms include *Melaleuca squarrosa*, *Epacris lanuginosa*, *Leptocarpus tenax*, *Lepyrodia tasmanica*, *Xyris operculata* and *Baumea rubiginosa*. *Gymnoschoenus* dense. Lichens rare, ± confined to dead hummocks. This vegetation is usually young and may be very frequently burnt (possibly at 3–4 year cycles) but older vegetation may be scrubby with tall *Melaleuca squarrosa* and *Leptospermum scoparium* and prominent lichens on peat.
12	High altitude, Central Plateau and NE Highlands	Grassy and herbaceous communities, often abutting buttongrass moorland. Angiosperms include *Poa* spp., *Astelia alpina*, *Olearia* spp., *Helichrysum* spp., *Galium australe*, *Geranium potentilloides* and *Wahlenbergia* sp. *Gymnoschoenus* rare, in large hummocks. Lichens ± absent.

TABLE 3
Description of Lichen Groups

Group number	Remarks
1	Ubiquitous species, occurring in most buttongrass moorland. However, *Cladonia subsubulata* is most abundant in heathy communities outside southwestern Tasmania.
2	Species confined to southwestern Tasmania.
3	Species mostly found at high altitude in southwesternTasmania, although *Cladia fuliginosa* and *Cladina mitis* also occur on high mountains elsewhere in other vegetation types, e.g. feldmark. The altitudinal range of *Wawea fruticulosa* is wider where it occurs as an epiphyte in forest or scrub.
4	Species characteristic of buttongrass moorland in southwestern Tasmania, but extending into high altitude communities elsewhere in Tasmania. *Cladia sullivanii* is more widely distributed in other vegetation formations (heathland and open forest).
5	Species widespread in heathlands and shrubby buttongrass moorland.
6	Species found mostly in high altitude buttongrass moorland outside southwestern Tasmania. Some, e.g. *Trapeliopsis colensoi*, are present in the southwest but in other vegetation.
7	Species found mostly in lowland buttongrass moorland outside southwestern Tasmania, also characteristic of sclerophyll forest, particularly in eastern Tasmania.

Umbilicaria and *Hypogymnia* occur on rock outcrops. In addition, pairs of related species or genera occur in similar habitats, e.g. *Parmelia saxatilis*, *Icmadophila ericetorum*, *Pycnothelia papillaria* and *Cladonia subulata* in Britain, *Parmelia signifera*, *Knightiella splachnirima*, *Pycnothelia caliginosa* and *Cladonia corniculata* respectively in Tasmania.

Approximately 25% of the species recorded in Tasmanian buttongrass moorland are cosmopolitan or bipolar and hence common to both regions, e.g. *Cladonia cervicornis* ssp. *verticillata*, *C. chlorophaea*, *C. pleurota*, *C. ochrochlora*, *C. pyxidata*, *C. rei*, *Cystocoleus niger*, *Hypotrachyna sinuosa*, *Multiclavula vernalis*, *Ochrolechia frigida*, *Protoblastenia rupestris* and *Rhizocarpon* cf. *geographicum*. However, many additional characteristic British blanket bog species (see James 1965, Gilbert 1972, 1974, 1980b), e.g. *Coelocaulon aculeatum*, *Alectoria nigricans*, *Pseudephebe pubescens*, *Trapeliopsis granulosa* and *Thamnolia vermicularis* also occur in Tasmania, but in related heathland, feldmark and other treeless vegetation at higher altitudes than those characteristic of buttongrass moorland. It is possible that these species may have been eliminated from lower altitudes (and hence buttongrass moorland) in Tasmania by repeated fires in the past.

Several ecological similarities are also evident between the Tasmanian and Northern Hemisphere vegetation. For example, the occurrence of alpine lichens to sea level in northern Scotland (Fletcher 1984) and Norway (P. M. Jørgensen, pers. comm.) is analogous to the situation in southwestern Tasmania. In both Tasmania and Britain, lichens are relatively impoverished in intact blanket bogs and heathlands. In Britain, they proliferate locally on track sides or peat banks and overhangs caused by erosion (Gilbert 1972, 1980a) and they are often best developed in similar situations in Tasmania.

SUMMARY

Buttongrass moorland occupies approximately 15% of the area of Tasmania. It contains a primarily terricolous lichen flora, occurring mostly on peat, dominated by the genera *Cladia*, *Cladonia*, *Siphula* and *Cladina*. Many additional species occur on large rock outcrops, loose stones and on emergent trees and shrubs which form a common feature of the moorland landscape.

Over 70% of the 89 lichens recorded from buttongrass moorland have essentially Southern Hemisphere distributions, analogous to the majority of the vascular flora. However, very few species are endemic. Several parallels are evident between Tasmanian buttongrass moorland and ecologically related blanket bogs and moors in the Northern Hemisphere. In addition to many generic similarities, approximately 25% of Tasmania's moorland lichens also occur in the Northern Hemisphere.

Most lichens in buttongrass moorland occur in well-drained, well-lit habitats and are best developed in shrubby communities or at high altitude. Favoured habitats include peat banks in clearings, decaying *Gymnoschoenus* hummocks and rotting stumps. Communities where the vascular plant cover is very dense or where the ground is boggy or periodically inundated are lichenologically depauperate.

For the most part fire has a disastrous effect on the lichen flora of buttongrass moorland, both directly and by destroying habitats and substrates, particularly peat. The outcome of repeated fires is likely to be similar to that found in Britain in analogous vegetation, with a severe loss of diversity and reduction of the flora to a few, impoverished thalli of ubiquitous, rapidly colonising species. Frequent and indiscriminate burning of Tasmania's buttongrass moorland could lead to the local extinction of many species.

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REFERENCES

ARCHER, A.W., 1983: *Cladonia chlorophaea* sens. lat. in southeastern Australia. *Bryologist* 86: 251–253.

ARCHER, A.W., 1986: The chemistry and distribution of *Cladonia capitellata* (J.D. Hook. & Taylor) Church. Bab. (Lichenes) in Australia. *Proc. Linn. Soc. N.S.W.* 108: 191–194.

BRATT, G.C., 1976: Lichens of South West Tasmania. I. Lichens of the buttongrass areas. *Tasm. Naturalist* 45: 1–4.

BRATT, G.C., 1978: Mosses and lichens. *In* Sharp-Paul, A. (Ed.): *LOWER GORDON RIVER SCIENTIFIC SURVEY*. Hydro-Electric Commission, Hobart: 1–24.

BROWN, M.J., CROWDEN, R.K. & JARMAN, S.J., 1982: Vegetation of an alkaline pan-acidic peat mosaic in the Hardwood River Valley, Tasmania. *Aust. J. Ecol.* 7: 3–12.

COPPINS, B.J. & SHIMWELL, D.W., 1971: Cryptogam complement and biomass in dry *Calluna* heath of different ages. *Oikos* 22: 204–209.

DUNCAN, F., 1985: *In ENVIRONMENTAL IMPACT STATEMENT ON TASMANIA'S WOODCHIP EXPORTS BEYOND 1988. WORKING PAPER 6*. Tasmanian Forestry Commission, Hobart.

FLETCHER, A., 1984: Conservation of terricolous lichens in Britain. *Brit. Lich. Soc. Bull.* 55: 1–4.

FOSTER, D.R., 1984: The dynamics of *Sphagnum* in forest and peatland communities in southeastern Labrador, Canada. *Arctic* 37: 133–140.

GALLOWAY, D.J., 1979: Biogeographical elements in the New Zealand lichen flora. *In* Bramwell, D. (Ed.): *PLANTS AND ISLANDS*. Academic Press, London: 201–224.

GELLIE, N.J.H., 1980: Fire ecology of buttongrass moorlands. *For. Comm. Tasm. Bull.* 6.

GILBERT, O.L., 1972: Field Meeting in Northumberland. *Lichenologist* 5: 337–341.

GILBERT, O.L., 1974: Reindeer grazing in Britain. *Lichenologist* 6: 165–167.

GILBERT, O.L., 1980a: Effect of land-use on terricolous lichens. *Lichenologist* 12: 117–124.

GILBERT, O.L., 1980b: A lichen flora of Northumberland. *Lichenologist* 12: 325–395.

GIMINGHAM, C.H., 1960: Biological flora of the British Isles. *Calluna Salisb. J. Ecol.* 48: 455–483.

GIMINGHAM, C.H., 1978: Calluna and its associated species: some aspects of co-existence in communities. *Vegetatio* 36: 179–186.

HAWKSWORTH, D.L., 1969: The lichen flora of Derbyshire. *Lichenologist* 4: 105–193.

HOBBS, R.J., 1985: The persistence of *Cladonia* patches in closed heathland stands. *Lichenologist* 17: 103–109.

JACKSON, W.D., 1968: Fire, air, earth and water — an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* 3: 9–16.

JAMES, P.W., 1965: Field Meeting in Scotland. *Lichenologist* 3: 155–172.

JARMAN, S.J., KANTVILAS, G. & BROWN, M.J., in prep.: *BUTTONGRASS MOORLAND IN TASMANIA*. National Parks and Wildlife Service, Hobart.

JØRGENSEN, P.M., 1983: Distribution patterns of lichens in the Pacific region. *Aust. J. Bot. Suppl.* 10: 43–66.

KANTVILAS, G., 1987: *Siphula jamesii*, a new lichen from south-western Tasmania. *Nord. J. Bot.* 7: 585–588.

KANTVILAS, G. & ELIX, J.A., 1987: A new species of *Cladia* (Lichenised Ascomycotina) from Tasmania. *Mycotaxon* 29: 199–205.

KANTVILAS, G., JAMES, P.W. & JARMAN, S.J., 1985: Macrolichens in Tasmanian rainforests. *Lichenologist* 17: 67–83.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984: *VEGETATION MAP OF TASMANIA*. Forestry Commission, Hobart.

PETERSON, R.H. & KANTVILAS, G., 1986: Three lichen-forming Clavarioid fungi from Tasmania. *Aust. J. Bot.* 34: 217–222.

TARVYDAS, R., 1978: Soils. *In* Sharpe-Paul, A. (Ed.): *LOWER GORDON RIVER SCIENTIFIC SURVEY*. Hydro-Electric Commission, Hobart.

WATSON, W., 1932: The bryophytes and lichens of moorland. *J. Ecol.* 20: 284–313.

WALKER, F.J., 1985: The lichen genus Usnea subgenus Neuropogon. *Bull. Br. Mus. Nat. Hist. (Bot.)*. 13: 1–130.

WETMORE, C.M., 1963: Catalogue of the lichens of Tasmania. *Rev. Bryol. et Lichenol.* 32: 223–264.

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APPENDIX

This appendix lists the 89 lichens which were recorded during the survey. Supplementary notes relate mainly to the occurrence of the species in buttongrass moorland but this has been placed into a broader Tasmanian context where the information is available. Genera where additional, unidentified species are known (or expected) are also indicated. These are mainly the saxicolous crustose groups.

(1) *Baeomyces arcuatus* Stirton: referred to as *B. fungoides* (Sw.) Ach. in Australasian literature; common and widespread in Tasmania on mineral soil; densely sorediate, sterile thalli are occasional on clay soils in buttongrass moorland; contains baeomycesic and squamatic acids.

(2) *Catillaria* s.lat. sp.: very common on decorticated, dead eucalypt stumps and trunks in copses or heathlands in buttongrass moorland; the species has an evanescent thallus and abundant, irregularly roundish, black, lecideine apothecia, to c. 1 mm diam.; spores are hyaline, very inconspicuously 1-septate, oblong to narrow ellipsoid, 7–12 x 2.5–5 µm.

(3) *Cladia aggregata* (Sw.) Nyl.: very common, highly polymorphic species found on soil, peat or rotting wood in virtually all vegetation formations in Tasmania; contains barbatic, stictic, norstictic or fumarprotocetraric acids.

(4) *Cladia fuliginosa* R. Filson: common on peat in alpine vegetation, rare in buttongrass moorland and confined to high altitude communities.

(5) *Cladia inflata* (F. Wilson) D. Galloway: common on wet, poorly drained peat and soil in heathlands and sedgelands from sea level to alpine altitudes, particularly in western Tasmania; contains fumarprotocetraric or fatty acids.

(6) *Cladia moniliformis* Kantvilas & Elix: endemic; common on very wet peat or mineral soil in buttongrass moorland in southwestern Tasmania from sea level to alpine altitudes (see Kantvilas & Elix 1987); contains homosekikaic acid.

(7) *Cladia retipora* (Labill.) Nyl.: very common and widespread on peat and soil in sedgelands, heathlands and open forests, from sea level to alpine altitudes.

(8) *Cladia schizopora* (Nyl.) Nyl.: confined to rotting, often charred wood, mostly in eucalypt forest; rare in buttongrass moorland.

(9) *Cladia sullivanii* (Müll. Arg.) Martin: very common and widespread on peat and soil in heathlands from sea level to alpine altitudes.

(10) *Cladina confusa* (R. Sant.) Follm. & Ahti: common and widespread on peat and soil in heathlands and forests, particularly at high altitudes; the species contains perlatolic and usnic acids but specimens from very shaded habitats contain very low concentrations of the latter and are grey in colour.

(11) *Cladina mitis* (Sandst.) Hustich: common on peat or over microshrubbery in alpine vegetation, occasional in high altitude buttongrass moorland; all Tasmanian specimens contain usnic and stictic acids.

(12) *Cladonia angustata* Nyl.: uncommon on well-drained fibrous peat in lowland heathland communities in southern, eastern and northern Tasmania; contains usnic and didymic acids.

(13) *Cladonia campbelliana* (Vainio) Gyelnik: widespread on well-drained peat, rotten wood or (rarely) mineral soil in heathlands and sclerophyll forests from sea level to subalpine altitudes; contains fumarprotocetraric acid.

(14) *Cladonia capitellata* (J.D. Hooker & Taylor) Church. Bab.: very common and widespread in sedgelands, heathlands and sclerophyll forests from sea level to alpine altitudes, often forming extensive mats on peat, mineral soil or in litter-filled rock crevices; three chemical races occur in Tasmania (Archer 1986): var. *capitellata* (containing usnic and thamnolic acids), var. *squamatica* Archer (containing usnic and squamatic acids) and var. *interhiascens* (Nyl.) Sandst. (containing usnic acid only); all but the last were recorded from buttongrass moorland; a form of var. *squamatica* which lacks usnic acid is locally common at Mathinna Plains in northeastern Tasmania.

(15) *Cladonia cervicornis* subsp. *verticillata* (Hoffm.) Ahti: very common and widespread on soil and peat in open forests and heathlands throughout Tasmania; extremely polymorphic; contains fumarprotecetraric acid.

(16) *Cladonia chlorophaea* (Flörke ex Sommerf.) Sprengel aggr.: widespread on peat or soil along roadsides or in forests or heathlands, uncommon in buttongrass moorland; three chemical strains were recorded during the survey: *C. chlorophaea* s.str.

(fumarprotocetraric acid), *C. cryptochlorophaea* Asah. (cryptochlorophaeic acid) and *C. merochlorophaea* Asah. (merochlorophaeic, 4-0-methyl-cryptochlorophaeic, ± fumarprotocetraric acids); of these *C. merochlorophaea* appears to be the most common (cf. Archer 1983); all three chemotypes may occur at a single locality.

(17) *Cladonia corniculata* Ahti & Kashiwadani: widespread and common on peat or mineral soil in heathlands and open forests throughout Tasmania, uncommon in buttongrass moorland; previously erroneously referred to in Tasmanian literature as *C. subulata* (L.) Wigg.; contains fumarprotocetraric acid.

(18) *Cladonia gracilis* subsp. *tenerrima* Ahta: uncommon in buttongrass moorland and found mainly in sclerophyll forest and scrub; contains fumarprotocetraric acid.

(19) *Cladonia kuringaiensis* Archer: uncommon in Tasmania and found on peat or rotting wood in heathlands or at the margins of forests; contains fumarprotocetraric and stictic acids.

(20) *Cladonia murrayi* W. Martin: widespread on peat and soil, usually at high altitudes in southwestern Tasmania; below c. 600 m, the species usually occurs as squamules only; contains thamnolic acid and skyrin.

(21) *Cladonia ochrochlora* Flörke: very polymorphic species, widespread on peat, rotten wood, litter and soil in heathlands and wet forests; contains fumarprotocetraric acid.

(22) *Cladonia pleurota* (Flörke) Schaerer: widespread in Tasmania on soil and peat, particularly at high altitudes; uncommon in buttongrass moorland and confined to shrubby communities or soil-filled crevices in large rock outcrops; contains usnic and isousnic acids and zeorin.

(23) *Cladonia praetermissa* Archer: locally abundant in the eastern half of Tasmania, mostly in lowland dry eucalypt forest; uncommon in buttongrass moorland and confined to shrubby communities; contains atranorin and fumarprotocetraric acid.

(24) *Cladonia pyxidata* (L.) Hoffm.: wide-ranging but uncommon on peat or mineral soil in heathland and open forest; contains fumarprotocetraric acid.

(25) *Cladonia ramulosa* (With.) Laundon: uncommon but widespread in wet heathlands and open forests on peaty soil; contains fumarprotocetraric acid.

(26) *Cladonia rei* Schaerer: apparently rare, at least in buttongrass moorland, and recorded only once during the survey (from Cox Bight, southwestern Tasmania); contains fumarprotocetraric and homosekikaic acids.

(27) *Cladonia scabriuscula* (Delise) Nyl.: common and widespread on peat, soil or litter in wet forests, rare in buttongrass moorland; contains fumarprotocetraric acid.

(28) *Cladonia southlandica* Martin: most common species of *Cladonia* found in buttongrass moorland, occurring on peat or rotting *Gymnoschoenus* hummocks in most communities from sea level to alpine altitudes; it is a rapid coloniser of scorched or burnt peat and is often found only as extensive mats of squamules; contains usnic and fumarprotocetraric acids.

(29) *Cladonia squamosula* Müll. Arg.: very common and widespread throughout Tasmania on rotting wood or (rarely) peat; locally abundant in buttongrass moorland on eucalypt stumps in heathland and copses; contains thamnolic acid, with barbatic acid in the apothecia.

(30) *Cladonia subdigitata* Nyl.: occasional on rotting wood and peat in buttongrass moorland, wet heathland, scrub and forest; contains usnic and thamnolic acids, and skyrin.

(31) *Cladonia subsubulata* Nyl.: very polymorphic, widespread species of buttongrass moorland, heathland and open forest; high altitude forms have slender, entangled podetia, ± dying at the base and lacking squamules; in the lowlands, the species usually has stouter, corymbose podetia, arising from a mat of squamules; contains thamnolic acid, with barbatic acid in the apothecia.

(32) *Cladonia tessellata* Ahti & Kashiwadani: uncommon on peat or mineral soil in heathlands or at forest margins; earlier records of *C. capitata* and *C. cariosa* from Tasmania probably refer to this species; contains fumarprotocetraric acid.

(33) *Cladonia weymouthii* F. Wilson ex A. Archer: common and widespread on peat and rotting wood in heathland and buttongrass moorland, mostly in western Tasmania; similar to *C. corniculata* but containing thamnolic, barbatic and didymic acids.

(34) *Cladonia wilsonii* A. Archer: rare but widespread on peat, soil or rotting wood in heathlands and wet forests; usually encountered as basal squamules only; contains atranorin and stictic acid.

(35) *Cystocoleus niger* (Huds.) Hariot: common in sheltered microhabitats on large rock outcrops in heathland and buttongrass moorland, mostly in southwestern Tasmania.

(36) *Flavoparmelia haysomii* (Dodge) Hale: abundant on large rock outcrops in buttongrass moorland, heathlands and open eucalypt forest, usually associated with *P. signifera*, *Xanthoparmelia* spp. and *Usnea torulosa*; the species most probably represents what has been referred to as *Parmelia caperata* in earlier Tasmanian literature.

(37) *Gymnoderma melacarpum* (F. Wilson) Yoshimura: common in Tasmania in wet forests on *Eucalyptus* bark, wood or litter; a distinctive form occurs in peat-filled rock crevices on quartzite outcrops in buttongrass moorland above c. 600 m in southwestern Tasmania; this form has terete, ± radially symmetric olive-brown squamules, densely packed to form ± rounded cushions, and rather resembles a diminutive *Sphaerophorus*.

(38) *Haematomma infuscum* (Stirton ex Bailey) R.W. Rogers: widespread wet forest twig species, occasional in high altitude buttongrass moorland on emergent *Casuarina*, *Baeckea* and other shrubs.

(39) *Heterodermia microphylla* (Kurok.) Swinsc. & Krog: locally common and widespread on rocks or (rarely) trees) in lowland, coastal heathlands and open forests; rare in buttongrass moorland; contains atranorin and terpenes.

(40) *Heterodermia obscurata* (Nyl.) Trevisan: uncommon, mostly on quartzite outcrops in coastal vegetation, association with *H. microphylla*.

(41) *Hypocenomyce australis* Timdal: a new record for Tasmania; common in dry sclerophyll forest but rare in buttongrass moorland and confined to charred wood of *Eucalyptus*, *Baeckea* and other Myrtaceae.

(42) *Hypogymnia lugubris* (Pers.) Krog: widespread and common, mostly at high altitudes, on trees, shrubs, large rock outcrops or over peat, litter and microshrubbery.

(43) *Hypogymnia turgidula* (Bitter) Elix: widespread and very common, mostly in wet forests; found in buttongrass moorland on emergent trees and shrubs.

(44) *Hypotrachyna sinuosa* (Sm.) Hale: widespread on trees or rocks in well-lit habitats in wet forests and heathlands.

(45) *Knightiella splachnirima* (J.D. Hooker & Taylor) Gyelnik: widespread but most abundant in southwestern Tasmania, on moist, peaty soil in buttongrass moorland, heathland and clearings in wet sclerophyll forest, from sea level to high mountain summits.

(46) *Lecidea coromandelica* Zahlbr.: saxicolous, mostly in high altitude heathlands and buttongrass moorlands, extending to sea level on Precambrian rocks in southwestern Tasmania.

(47) *Lecidea laeta* Stirton: very abundant throughout Tasmania in well-lit, corticolous habitats in heathland, sclerophyll forest and rainforest; found in buttongrass moorland on twigs of emergent shrubs, particularly *Melaleuca*, *Leptospermum* and *Baeckea*.

(48) *Lecidea leptocarpa* Nyl. in Church. Bab. & Mitten aggr.: wide-ranging and polymorphic species on rocks throughout Tasmania. Very common in buttongrass moorland on large outcrops as well as small, loose pebbles; the ± contiguous, black apothecia are sometimes responsible for the black streaks on white quartzite boulders; additional species of Lecideaceae s.lat. have been recorded from Precambrian metamorphic rocks and limestone in buttongrass moorland but will be reported separately.

(49) *Lecidella elaeochroma* (Ach.) M. Choisy: very common on twigs and trunks in high rainfall areas from sea level to alpine altitudes; often the most common epiphyte of emergent trees and shrubs (particularly *Banksia*) in buttongrass moorland.

(50) *Lithographa* sp.: first record of the genus for Australia; uncommon and apparently confined to southwestern Tasmania on small, loose quartzite stones on gravelly slopes in buttongrass moorland; the species has an endolithic thallus and hyaline, 15–17 x 8–8.5 µm spores.

(51) *Menegazzia aeneofusca* (Müll. Arg.) R. Sant.: widespread on large rock outcrops, mostly at subalpine and alpine altitudes, but extending to sea level in sheltered habitats, particularly in southwestern Tasmania; typically recognised by the dark olive-brown or blackened upper cortex but thalli from exposed habitats may be bleached pale greenish grey.

(52) *Menegazzia confusa* P. James: local in dry sclerophyll forest; uncommon in buttongrass moorland and recorded from emergent shrubs in lowland, coastal communities; closely related to *M. platytrema* and differing chiefly by the presence of fatty acids instead of stictic acid in the medulla.

(53) *Mengazzia platytrema* (Müll. Arg.) R. Sant.: widespread in well-lit habitats in rainforest and sclerophyll forest; the most common epiphytic *Menegazzia* in buttongrass moorland, occurring on *Banksia*, *Hakea* and other shrubs; additional species of *Menegazzia*, e.g. *M. subbullata*, *M. subpertusa* and *M. weindorferi*, may also occur in buttongrass moorland near wooded or scrubby margins, at high altitude or on occasional, old, fire-protected trees.

(54) *Micarea* sp.nov.: a new species, endemic to Tasmania and related to *M. ternaria* from the Northern Hemisphere (B.J. Coppins, pers. comm.); widespread in southwestern Tasmania from sea-level to high mountain summits in buttongrass moorland, heathland and feldmark; the species acts as a stabiliser of peat and soil on very open, gravelly slopes and is usually associated with *Siphula jamesii* and *S. decumbens*.

(55) *Multiclavula vernalis* (Schw.) Petersen: a new record for Tasmania (see Petersen & Kantvilas 1986); locally abundant in buttongrass moorland in southwestern Tasmania on moist soil along streams, drainage channels and tracks, on muddly flats between *Gymnoschoenus* hummocks and on raised earth turrets built by lobsters (e.g. *Parastacoides* spp.).

(56) *Neofuscelia stygioides* (Nyl. ex Crombie) Esslinger = *Parmelia stygioides* Nyl. ex Crombie: widespread, essentially alpine, saxicolous species, occasional in buttongrass moorland on large rock outcrops, mostly in southwestern Tasmania.

(57) *Ochrolechia frigida* (Sw.) Lynge: new record for Tasmania; widespread in alpine moorland and heathland over soil and microshrubbery; rare in buttongrass moorland and confined to high altitude communities in southwestern Tasmania.

(58) *Omphalina* sp.: locally abundant and widespread on moist, peaty soil in many buttongrass moorland, heathland and sclerophyll forest communities, often fruiting most prolifically soon after a fire; the species has a granular, *Botrydina*-type thallus.

(59) *Parmelia signifera* Nyl.: very common and widespread on large rock outcrops, particularly at high altitudes; frequently becoming blackened on the upper surface with conspicuous white sigmoid pseudocyphellae.

(60) *Peltigera dolichorhiza* (Nyl.) Nyl.: common on the forest floor, logs and tree buttresses in wet forests; rare in buttongrass moorland and confined to shaded habitats in copses.

(61) *Pertusaria* sp.: most probably a new species with a thick, pale yellow thallus containing usnic and gyrophoric acids and pale red-brown spores, 100–210 x 45–90 µm, 1 per ascus; common in southwestern Tasmania in open, heathy vegetation above c. 700 m where it forms a crust over peat, litter and low shrubs, e.g. *Donatia* and *Pentachondra*; fertile material is rare.

(62) *Placopsis trachyderma* var. *clavifera* (Lamb) P. James: uncommon, recorded from fresh clay at the margin of buttongrass moorland in southwestern Tasmania; additional species of Placopsis (e.g. *P. parellina*, *P. gelida*) occur in the vicinity of buttongrass moorland along roadsides on clay and stones but the genus has not been recorded from peat and is rare in this vegetation type; in Tasmania, *Placopsis* is most common and diverse in subalpine or alpine heathlands and boulder fields but is still very poorly known.

(63) *Placynthium nigrum* (Huds.) S.F. Gray: new record for Tasmania; restricted to limestone and locally abundant in buttongrass moorland in southwestern Tasmania.

(64) *Protoblastenia rupestris* (Scop.) Steiner: new record for Tasmania; rare and recorded only from limestone outcrops in buttongrass moorland near the Maxwell River, southwestern Tasmania.

(65) *Protoparmelia petraeoides* (Nyl. ex Hue) Hertel: widespread on rocks throughout Tasmania, common in buttongrass moorland on large outcrops, associated with Lecidea leptocarpa, *Xanthoparmelia* spp. and *Parmelia* signifera.

(66) *Pycnothelia caliginosa* D. Galloway & P. James: local on mountains in southwestern Tasmania and recorded in buttongrass moorland from peat-filled rock crevices, decomposing Gymnoschoenus hummocks or Donatia bolsters, and from moist sandy soils; associated species include Siphula decumbens, *S. jamesii*, *Cladia* spp., *Micarea* sp., *Cladina mitis*, *Cladonia southlandica* and *C. murrayi*.

(67) *Rhizocarpon* cf. *geographicum* (L.) DC.: widespread on rocks, especially at high altitude; locally abundant in buttongrass moorland on large outcrops, associated with species of Lecideaceae and *Xanthoparmelia*.

(68) *Siphula complanata* (J.D. Hooker & Taylor) R. Sant.: local in alpine moors and heathlands, usually on very wet, periodically inundated peaty soil; occasional in buttongrass moorland at its upper altitudinal limits;

contains porphyrilic acid and methyl porphyrilate; a related, undescribed species, containing porphyrilic acid only, occurs in dry, peat-filled rock crevices in alpine quartzite rock outcrops in southwestern Tasmania.

(69) *Siphula decumbens* Nyl.: the most common *Siphula* in Tasmania, recorded on peat or mineral soil in buttongrass moorland in southwestern Tasmania and in alpine vegetation on high mountains elsewhere; lobe morphology is extremely variable, ranging from loose, narrow and straplike (in shaded sites beneath shrubs or sedges) to crowded, short and rounded (in exposed habitats); the species commonly forms extensive chalky white swards and associated lichens include *Cladia aggregata*, *C. retipora*, *Cladonia southlandica*, *C. murrayi* and *Siphula jamesii*; contains thamnolic acid (thallus K+ yellow).

(70) *Siphula fragilis* (J.D. Hooker & Taylor) J. Murray: widespread on muddy soil in or around shallow pools on high mountain plateaux; uncommon in buttongrass moorland and confined to high altitude communities; contains no substances detectable by TLC.

(71) *Siphula jamesii* Kantvilas: common on exposed, very wet peat or mineral soil, particularly on bare gravelly slopes in buttongrass moorland, feldmark and heathland from sea-level to alpine altitudes in southwestern Tasmania (Kantvilas 1987); associated species include *S. decumbens*, *Cladia moniliformis* and *Micarea* sp.nov.; contains no substances detectable by TLC.

(72) *Siphulastrum triste* Müll. Arg.: new record for Tasmania; uncommon or overlooked, amongst mosses on rock outcrops in alpine and subalpine vegetation; rare in buttongrass moorland.

(73) *Sphaerophorus tener* Laurer: the most widespread and common species of the genus, occurring in rainforest, wet scrub, heathland and alpine vegetation; in buttongrass moorland, it is restricted to high altitude rock outcrops or heathy communities where it overgrows bryophytes and low shrubs; saxicolous individuals are extremely polymorphic and forms which are tufted or where the lateral branches are eroded may have been previously misidentified as *S. fragilis* or *S. globosus*, species recorded from Tasmania in the 19th century (Wetmore 1963) but not found subsequently; additional *Sphaerophorus* species, e.g. *S. melanocarpus* and *S. ramulifer*, may also occur in sheltered microhabitats on rock outcrops in high altitude vegetation.

(74) *Stereocaulon ramulosum* (Sw.) Räuschel: widespread on rocks throughout Tasmania in open forests, heathlands, alpine vegetation and along roadsides; uncommon in buttongrass moorland and found mostly in high altitude communities.

(75) *Thysanothecium scutellatum* (Fr.) D. Galloway = *T. hyalinum* (Taylor) Nyl.: common in dry sclerophyll forest on eucalupt charcoal or wood, associated with *Cladia schizopora* and *Cladonia squamosula*; rare in buttongrass moorland and confined to lowland coastal communities in northern and eastern Tasmania.

(76) *Trapeliopsis colensoi* (Church. Bab.) G. Schneider: new record for Tasmania; locally common on exposed banks of peat or sandy soil in clearings, along tracks or on rotting *Gymnoschoenus* hummocks, in heathlands or open sclerophyll forest; recorded mostly above c. 700 m in the Central Highlands.

(77) *Umbilicaria cylindrica* (L.) Delise in Duby: common and widespread on alpine and subalpine rocks, extending to sea-level on quartzite boulders in buttongrass moorland in southwestern Tasmania; associated species include *Usnea torulosa*, *Parmelia signifera* and *Xanthoparmelia* spp.

(78) *Umbilicaria polyphylla* (L.) Baumg.: locally common on quartzite outcrops in southwestern Tasmania in alpine and subalpine vegetation or in buttongrass moorland above c. 600 m; associated species include *U. cylindrica*, *Neofuscelia stygioides*, *Parmelia signifera* and *Xanthoparmelia* spp.

(79) *Usnea arida* Motyka: very polymorphic; the most common corticolous *Usnea* in high rainfall regions of Tasmania, occurring in buttongrass moorland on emergent shrubs of *Banksia*, *Hakea* and *Casuarina*, associated with *Hypogymnia* and *Menegazzia* spp.; thalli from exposed, windswept habitats are often very inflated and lack lateral branches; contains usnic and salazinic acids.

(80) *Usnea torulosa* (Müll. Arg.) Zahlbr. = *U. glomerata* Motyka: widespread and common on rocks throughout Tasmania; all populations studied from buttongrass moorland contain barbatic acid, a chemical strain reported by Walker (1985) as being the least common; psoromic and squamatic acid strains also occur in Tasmania but appear to be confined to high mountains; in exposed habitats, the species may be partially blackened and resemble a *Neuropogon*.

(81) *Waweafruticulosa* Henssen & Kantvilas: locally abundant throughout western Tasmania in wet forest, heathland and scrub; uncommon in buttongrass moorland and confined to moist peat in some high

altitude communities, or to the papery bark of *Leptospermum* or *Melaleuca* in wet copses.

(82) *Xanthoparmelia adhaerens* (Nyl.) Hale: common on Precambrian rock outcrops in buttongrass moorland in southwestern Tasmania, also recorded elsewhere in the island; usually associated with *X. mougeotina*; contains usnic and stictic acids (major substances).

(83) *Xanthoparmelia alexandrensis* Elix & Johnston: apparently rare and known from a single locality near Mt Tyndall, western Tasmania, where it occurs on conglomerate boulders in buttongrass moorland; contains usnic and norstictic acids (major substances).

(84) *Xanthoparmelia amplexula* (Stirton) Elix & Johnston: widespread on rock outcrops in buttongrass moorland, heathland and sclerophyll forest, usually associated with other *Xanthoparmelia* spp.; contains usnic acid, norlobaridone and loxodin.

(85) *Xanthoparmelia isidiigera* (Müll. Arg.) Elix & Johnston: widespread on rock outcrops throughout Tasmania; contains usnic and salazinic acids (major substances).

(86) *Xanthoparmelia mougeotina* (Nyl.) D. Galloway: very common throughout Tasmania on stones and large rock outcrops; contains usnic and stictic acids (major substances).

(87) *Xanthoparmelia neotinctina* (Elix) Elix & Johnston: widespread on rocks in Tasmania, particularly in drier areas but uncommon in buttongrass moorland; contains usnic and norstictic acids (major substances).

(88) *Xanthoparmelia scabrosa* (Taylor) Hale: local on rock outcrops, particularly at high altitudes; contains usnic acid, norlobaridone and loxodin.

(89) *Xanthoparmelia tegeta* Elix & Johnston: widespread in Tasmania and locally common on Precambrian outcrops in buttongrass moorland in southwestern Tasmania; contains usnic and stictic acids (major substances).

FOOD AND AGRICULTURE IN THE NEW COLONY OF VAN DIEMEN'S LAND, 1803 TO 1810

by Trevor D. Semmens

(with four tables and one text-figures)

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The new settlement of Van Diemen's Land and its first eight years are looked at in the light of the feeding of this young colony, and the development of agriculture to allow for sufficiency in food. For many reasons development was slow and progress limited.
Key Words: food, agriculture, Van Diemen's Land, famine.

".... For Wise and Good reasons to promote the Interest of the British Nation and Secure the Advantages that may be derived from the Fisheries, etc., etc., in the Colony ... to form a Settlement On the South Part of this Coast, or Isles Adjacent, to Counteract any Projects or plans the French Republic may arrainge ... [I] *intrust you with the Charge of forming Such Establishment"* ...
Part of Order given to Lieut Bowen, 29 March 1803 (H.R.A. III(1): 190–191)

IN THE BEGINNING ... THE DEPENDENT COLONY

At Settlement — Risdon Cove

After several abortive attempts, settlement of Risdon Cove by Lieut John Bowen and his small party occurred on 8 September 1803. This settlement started the new colony.

In instructions given to Bowen on 28 March 1803 (H.R.A. I(4): 152), the following had specific regard to food and agriculture:

> "After taking measures to secure yourself and people and stores you will proceed to clear ground on the public account for the cultivation of wheat and other plants."
> "You are to inform yourself of the nature of the soil, what proportions of land you find proper for the cultivation of wheat, barley and flax ... what quantity of cattle can be taken care of ..."
> "You are to fix the settlers ... [the] ground you may intend to allot for cultivation on the public account; and as they are free settlers you will, as they are the first, allot 200 acres (81 ha) to each family and victual them for eighteen months. They are to be allowed the labour of two convicts each during that time, and to be supplied with such portions of seed, grain, garden seeds and stock as can be spared; and also tools."

Instructions were reissued on 10 June 1803 and were much less liberal (H.R.A. III(1): 193) viz.:

> "To have town lots of 5 acres (2 ha) each, on lease 14 years, and when circumstances will allow to have a grant of 100 acres (40.47 ha) each, subject to the usual quit rents. To be victualled 12 months from the time of taking possession of their town lots. To be allowed the labour of 2 convicts victualled for the same term; after which they and their families are to be of no further expense to Government."
> "To have 2 ewes each, 6 bushels (0.22 m^3) of seed wheat, a proportion of tools, nails, clothing and such garden seeds as can be spared ..."
> "Should any unforeseen circumstances ... induce the Commandant to continue them longer on the stores from loss of crops, etc., he is at liberty to do it ..."

Additional instructions furnished in a "memorandum for Mr. Bowen" included the following:

> "Be careful the people get their ration given clear — 4 lbs (1.82 kg) pork and 7 lbs (3.18 kg) biscuit a week."
> "Slops are to be issued in December and June ..." [This refers to ready made or cheap clothing, not food "slops"!]

"Everyman except ... to be kept employed at the public labour in securing the provisions and stores ..."

As at 27 September 1803 the Risdon Cove community consisted of "49 souls". A return of livestock landed showed: Government stock — 1 bull, 8 cows, 2 rams, 16 ewes, 4 ewe lambs, 3 wether lambs. Private stock — 1 mare, 8 goats, 38 pigs, 7 sheep, 1 cow.

In a short time the two free settlers had their blocks ready for sowing and the Surgeon, Mountgarrett, had a few acres ready. But there was no ground prepared for cultivation on Government account. The latter was due to the fractious nature and the lack of ability of the convicts. (The Administrator would have profited from reading Francis Bacon's "Essay on Plantations" where he said, "It is a shameful and un-blessed thing to take the scum of people and wicked condemned men to be the people with whom you plant a colony" (Barrett 1936).)

Settlement at Sullivan Cove

On 16 February 1804, Lieut Governor Collins arrived at Risdon Cove and was most disappointed at its positioning for a permanent settlement. Next day he and others "went to examine a plain on the S.W. side of the river" (Nicholls 1977). They were delighted with this site which was called Sullivan Cove. So Collins settled there. It had a good water supply and the loading and unloading of ships was not difficult, and the soil at least equal to that at Risdon Cove.

Governor Collins viewed his expedition as an attempt to establish a new colony. It consisted of free settlers who were to till the land and raise crops and cattle so as to make the colony independent in the matter of food supplies. It was not to be thus independent in his period of office.

The first General Orders were issued by Collins on 28 February 1804 (HRA III(1): 219) and included the following as regard provisions:

"The storekeeper will issue the following weekly ration until further orders, viz:–
To civil, military, free settlers and prisoners —
7 lb. (3.18 kg) Beef or 4 lb. (1.82 kg) Pork
7 lb. Flour
6 oz. (0.17 kg) Sugar
To women two-thirds, children above five years half and children under five years one fourth of the above rations.
The issuing days for provisions will be in future Tuesdays and Saturdays.
The military will receive half a pint (0.28 l) of spirits daily as before."

They were urged "under pain of being severely punished", to keep the supply of pure running water from being polluted. To store all the provisions brought in, a temporary wooden storehouse was erected on Hunter's Island.

A site three miles (4.8 km) away was picked for the Government Farm and was named Farm Bay (now Cornelian Bay) and the settlers were located in the next bay, Stainforth's Cove (now New Town Bay).

The settlers were entitled to land grants of 100 acres (40.47 ha) each, which were to be made by the Governor of New South Wales (N.S.W.) on the recommendation of Lieut Governor Collins. In addition, they and their families were to be victualled from the public stores for twelve months, and assisted with tools, seed grain and the services of whatever spare convicts could be assigned to them. Collins was anxious they should prove "by their exertions, abilities and propriety of conduct that they are deserving of being trusted with stock and are likely to support themselves independent of the public stores", before being eligible for the land grant. In spite of lack of convict labour, the settlers in the first season harvested a crop which gave them a small surplus over the requirement for seed. Meanwhile, on the Government Farm a lot of work had been done. In July 1804 there were 19.5 acres (7.9 ha) of wheat, 1.75 acres (0.29 ha) of oats and 2.25 acres (0.91 ha) of rye. Interestingly, all the seed grain brought out from England was spoilt (or was poor to start with) and did not germinate. (Note: At Port Phillip, the aborted settlement prior to Sullivan Cove, "...18 or 20 different sorts of [garden] seeds which were put into the ground, not one succeeded" (HRA III(1): 221).) Fortunately, further supplies which had been purchased at Cape Town and some from Sydney proved satisfactory.

Because of the scarcity of labour and the urgency of getting agricultural work underway, Collins allowed the convicts to work with the settlers in their spare time. Without the convicts' aid the settlers would have made little progress. Even at this very early stage, "labour troubles" beset the small community, forcing Collins on 22 June 1804 to issue a General Order fixing the price of labour (HRA III(1): 270). Some agricultural wage rates were:

"For felling and burning of timber, per acre	£1/10/0
Grubbing and burning, per acre	4/0/0
Breaking up new ground 3d. per rood, per acre	2/0/0

Chipping ground 2d. per rood, per acre	1/6/8
in seed 1 and a half pence per rood, per acre	1/0/0
Breaking up stubble ground 2d. per rood, per acre	1/6/8
Digging garden ground, per rood	6d.
Reaping an acre of wheat	10/0
Threshing wheat per bushel	8d."

Meanwhile the two settlers at Risdon Cove, Birt and Clark elected to stay on there till their crop was harvested, after which both moved out to Sydney and Sullivan Cove respectively.

The next shipment of livestock arrived from Sydney on 25 June 1804 after an extremely tempestuous passage of 32 days. Many of the stock died.

A return of livestock in the colony, dated 4 August 1804 showed:

horses	nil	bulls	3	cows	10
calves	8				
rams	4	ewes	34	wethers	2
lambs	21				
he-goats	1	she-goats	10	kids	7
boars	6	sows	21	pigs	29
geese	12	ducks	31	turkeys	12
fowls	123				

Of the above, all the cattle and sheep belonged to the Government, with the remainder chiefly in the hands of the officers. Generally each settler possessed only a few head of poultry.

The shortage of livestock was relieved by the arrival, on 8 August 1804, of a shipment from India. In consisted of 130 cows, 60 oxen, 1 bull, 1 stallion, 3 mares, 59 sows and 2 boars. The cows were the small Bengal breed — but when crossed with English bulls produced animals of better breed and larger size. These were all for the Government and were sent to the Government Farm. The settlers had to purchase stock how and when they could — chiefly from vessels which happened to visit the port for the purposes of trading. Within the next twelve months, Lieut Governor Collins realised the necessity of assisting settlers with stock, which were then sold to them on the express condition that they not be alienated till the second generation.

At this time there was a severe shortage of specie (coinage) in the colony, and as a result workers bartered their labour for a surprising variety of items. These included soap, wine, meat, flour, clothing, shoes, cows, pins, buttons and rum, which was one of the favoured items (Barrett 1936). As a result, it was found necessary to fix the price at which articles could be paid for labour. The following were specified: salted beef, 9d. per pound; salted pork, 1/– per pound; kangaroo, 8d. per pound; flour, 1/– per pound; and wheatmeal, 6d. per pound (see table 1).

Methods of agriculture were necessarily very primitive. The settlers had no horses of their own and no ploughing was done. The ground was roughly cleared and then broken up with a hoe and the seed roughly sown, or, as often as not, simply chipped in. It was hard work indeed.

Over a period of time (see section "Land Grants and Agriculture"), some of the settlers and civil and military officers were granted land. These grants date from 15 August 1804. Because of trouble experienced in N.S.W. by the N.S.W. Corps, officers were allowed to engage in agriculture, but were strictly forbidden to trade.

Settlement at Port Dalrymple

In November 1804, the first settlement was temporarily set up at Outer Cove (now George Town), but because of gales and uncertainty regarding the dangerous entry into the Tamar River, an amount of stores, spirits and salted provisions were landed on Green Island. Shortly afterwards a further settlement was made at Yorkton but this was also found not particularly suitable for a permanent settlement. Thus the site now known as Launceston was settled.

The first shipment of livestock to this new settlement arrived in March 1805. However, the stock suffered badly on the stormy passage and there were landed only one mule, two oxen, two calves, three sheep, two boars and thirteen sows. Shortly afterwards a large consignment from India was diverted to Port Dalrymple. Landed were 612 cows, 10 calves and 34 ewes together with a quantity of rice and salted meat. The cost of this shipment was immense — £15 350. £25 was paid for each cow landed and £5 for each calf. Nine hundred and ten animals were put on board, but 298 died during the voyage. The winter cold took a heavy toll on what cattle were left and only 250 remained at the end of 1805. Within a few days another shipment arrived. It consisted of 120 ewes, 2 rams, 6 cows, 2 bulls, 1 mare and 1 horse. In this regard Governor King assisted Lieut Governor Paterson and his small settlement at Port Dalrymple more than Collins at Sullivans Cove.

In spite of this help, the settlement did not prosper and in 1806 there were only three settlers established (in 1808 still only three and by 1810 only sixteen). However, Mr Mountgarrett, the Surgeon (formerly of Risdon settlement), and

TABLE 1
Food Costs

During the early years in the colony food was very expensive as shown by prices relative to 1985 wage rates. Note: a wage of £50 per annum was good for workers in that early 1800's period.

Item	Actual cost	Price relative at 1985 wage rates
Meat — salted beef	9d per lb	$34.34 per kg
— salted pork	1/– to 3/– per lb	$42.92 to $128.76 per kg
— kangaroo	8d to 1/– per lb	$30.04 to $42.92 per kg
Bread — 1st quality	8d to 2.6 per lb	$30.04 to $107.30 per kg
— inferior	4 1/2 d per lb	$16.10 per kg
Tea	£6/6/– per lb	$5407.92 per kg
Biscuit	4/– per lb	$171.68 per kg
Maize	3/6 per lb	$150.22 per kg
Sugar	10d to £1 per lb	$35.77 to $858.40 per kg
Rice	2/6 per lb	$107.30 per kg
Potatoes	1/6 to 2/– per lb	$64.38 to $85.84 per kg
Corn	7/– per lb	$300.44 per kg
Soap	12 1/2 d per lb	$43.64 per kg
Tobacco	£1 to £2/10/– per lb	$858.40 to $2146 per kg
Wheat	25/– to £6+ per bushel	$13 413 to $64 369 per m^3
Barley	£5 per bushel	$53 658 per m^3
Pumpkin	9/– each	$175.59 each
Spirits	25/– to £2 gallon	$107.20 to $171.52 per litre

Mr Riley, the Storekeeper, had been most energetic and in 1806 had sown 53 acres (24 ha) of wheat, 23 acres (10.4 ha) of barley and 4 acres (1.8 ha) of potatoes. No cultivation had been undertaken on Government account though it possessed virtually all the livestock. Of the population of 276 (August 1806), all except three adults and two children were victualled from the Government store.

THE FAMINE — APRIL 1805 TO DECEMBER 1807

For nearly three years — from April 1805 to December 1807 — the Derwent settlement and, for nearly that period, Port Dalrymple were very short of provisions. For most of the time both settlements were on a very much reduced ration and at some periods they were on the verge of famine. Supplies of meat were considerably augmented by the issue of kangaroo and emu: indeed the kangaroo was the salvation of the settlements. Small shipments of provisions were received at intervals from Port Jackson, and some rice from India, and these helped to eke out supplies, but it was not until the early part of 1808 that the settlements were placed beyond the reach of want, and the harvest of 1808 at the Derwent settlement in fact provided a small surplus for export to Port Jackson.

During these three years the colony made no progress whatever. Work was practically at a standstill, for little labour could be expected from prisoners on a ration that was hardly sufficient to keep body and soul together. Cultivation was neglected because a large proportion of the assigned servants were hunting kangaroos, and there was not sufficient labour to till the fields. Besides, the masters found it more profitable to sell kangaroo to the Government at 1/– per pound than to take the risk of growing wheat to sell at 10/– per bushel.

The general orders issued from June 1805 to 1808 give a very vivid picture of the state of the Derwent settlement. The orders are very numerous, are nearly all concerned with the subject of rations, and are most melancholy reading. Port Dalrymple was in exactly the same straits, but this survey is chiefly confined to the Derwent, because we have more information about that part of the island.

On 4 March 1805, the returns of the Deputy Commissary showed that there was only 21 weeks supply of salt meat in store, and as no shipment arrived during the next few weeks the issue of beef was reduced by half. To save the flour, the issue was reduced to 6 lbs (2.72 kg), and to make up the ration, 6 lbs (2.72 kg) of wheat were issued. On 14 June, even at the reduced ration, there was only 12 weeks supply of pork in the store, 22 weeks of flour and 7 weeks of wheat. Within a few days the *Richard and Mary* brought two weeks supply of flour and five weeks of beef and pork, and the next month the *Sophia* brought three weeks supply of pork. Unfortunately, nearly half of the *Sophia's* consignment had to be jettisoned in a gale to lighten the ship. In order to save the salted meat as much as possible, on 2 August the Lieut Governor notified that kangaroo would be received into store at 1/– per pound and issed at the rate of 2 lbs (0.91 kg) for one of salted meat. The balance of the ration was made up of 2 lbs flour, 2 lbs wheatmeal, 2 lbs wheat and 12 oz. (0.34 kg) sugar. By the end of the month the flour was cut out of the ration, the wheatmeal was expended, and the deficiency was made up by an extra 1 lb each of wheat and rice, and an increase to 1 lb of sugar of which there was a good supply.

Early in August 1805, Rev. Knopwood also records a shortage in another article necessary as a beverage and a means of barter (Nicholls 1977) — "not a drop of spirits in the Colony". On 7 September the wheat was expended also, and flour had to be issued instead. On 14 September the first "soup kitchen" was opened in Hobart Town. The general order read,

> "The Lt. Governor having directed that a quantity of Kangaroo should be boiled into soup at the General Hospital one quart thereof will be issued daily at the hour of 12 to such persons as choose to apply for same, and until further orders."

This soup was made from the fore-quarters, on which there was little meat, and which were unsuitable for issue as rations.

Small shipments by the *Richard and Mary*, and the *Governor Hunter* in October, and a large consignment by the *Sydney* in November enabled the Lieut Governor to increase the weekly issue to nearly the full ration. Hours of labour had been relaxed during the shortage, but the Governor found no increase in the work being done on the improved ration. Some maize arrived by the *Sophia* in January 1806. The harvest of 1805 was only about 300 bushels (10.92 m^3) and that of 1806 was not likely to be much more. Collins offered 10/– per bushel for it, and saying that "better grain could no-where be produced" recommended "all persons holding land to make every possible progress in the cultivation thereof".

By April 1806 provisions were getting very low and the rations had to be reduced again. And two unfortunate circumstances were to add to the distress of the colony. Large quantities of salted pork received by various vessels were found to be quite unfit for human consumption. Collins wrote on 20 April 1806 (HRA III(1): 357),

> "I have been for a considerable time past issuing salted pork that under no other circumstances than those in which I unfortunately found myself would have been received into His Majesty's Stores, or considered as possible to be eaten."

The *Sophia's* consignment from Norfolk Island was so bad that 16 000 lbs (7264 kg) (three months' supply) was condemned, being "rancid, rotten and unfit to eat". This was occasioned by lack of salt and leaky casks, but in many cases the Government stores had been imposed upon, as casks were found to contain merely heads and feet, or else good pieces at either end, and in the middle meat that ought to have been destroyed.

In March 1806 the great granary of the colonies — the Hawkesbury River district — experienced disastrous floods. Stacks of grain which had been harvested from 4500 acres (1821 ha) of wheat and barley were swept away and 2424 acres (981 ha) under maize were ruined, so that the Mother Colony herself was faced with a very serious prospect. Governor King at once sent off to India for a cargo of rice, but it was several months before it arrived. King therefore did his best to send to the Derwent and Port Dalrymple settlements whatever immediate help was possible from his scanty resources by means of his small vessels. On 16 June the brig *Venus*, one of the two vessels which King had hurried off, was piratically seized at Port Dalrymple by the mate and crew before she had unloaded any of her cargo of much-needed provisions.

The first execution in Tasmania was occasioned by a robbery of the Government stores

at Port Dalrymple. On 18 January 1806, three soldiers and James Keating, cooper at the stores, broke open three casks and stole 35 lbs (15.9 kg) of pork. All were sentenced to death, and Keating was sent to Hobart Town and was executed publicly on 14 April. Theft was a serious (though common) crime in any circumstances, but robbery of the stores when the colony was in such sore straits, and by those whose duty it was to guard them, was indeed a crime of great magnitude.

Prices of provisions inevitably soared. Thus, by a general order of 9 June, the number of public bakers was limited to four. They were to have the sole right to bake bread for the inhabitants for a period of six months. A standard loaf was to be produced at a fixed price. No bread was to be made "during the present scarcity" of a "finer quality than a sample household bread which was produced by Richard Coleman and approved by the Magistrates, and for which the bakers are allowed to charge 8d. per lb., and 4 and a half pence for bread of an inferior quality" (HRA III(1): 542). The price of wheat was fixed at not more than 25/– per bushel (3.64×10^{-2} m^3). The penalty on conviction for "offering or giving more than the above mentioned prices" was £10.

By the end of July the provisions had been considerably reduced, and the ration consisted of 8 lbs (3.6 kg) of kangaroo meat and only 3 lbs (1.37 kg) of flour of wheat for the civil, military and free persons, and 2 lbs (0.91 kg) of wheat to the male prisoners.

A small supply was received early in August via the *Governor Hunter* from Port Jackson, and a liberal ration of salted pork and beef was issued, with a few pounds of meal and maize. There was no grain in the settlement, so Collins thought it his duty to write to the Commandant at the Cape of Good Hope urging him to send whatever supplies he could. Tea was also a very scarce commodity. Knopwood's notes of 25 August 1806 stated (Nicholls 1977), "Captain Sladen's sale was this morn, and one pound of tea was sold at the enormous price of six guineas a pound and bought by Lt. Lord."

The scarcity of provisions led to frequent robberies and depradations, including the slaughter of both public and private stock. Rev. Knopwood on 27 September 1806, had this to say about the situation:

> "The prisoners very greatly distressed for provisions, not any flour, meal or maize in store. This day things sold at the following price:– Biscuit 4/– per lb. meal 3/6 do. maize 3/3 do. tobacco not fit to be made use of 2/6 per inch. The Colony very greatly distressed for everything and everybody crying out for the want of bread, sugar 5/– per lb., rice 2/6 per lb. and kangaroo at 1/– per lb." (Nicholls 1977).

The Deputy Judge Advocate, Mr Bate, who had recently arrived, sold flour for 6/– per lb. Often men went fishing for it was their only chance of getting something to eat. The whaler *King George* arrived on 6 October with a small supply of salted meat, but no grain or flour, a supply which relieved the situation a little.

Shortly afterwards (13 October) Knopwood wrote, painting a terrible picture of conditions:

> "It is truly lamentable to see the distress that the people are in not a man able to do any work, what few there employed in unloading the "King George" the Lt. Governor is obliged to give them pork and beef 4 lb a man all our poultry are dying having nothing to give them. The poor piggs etc etc are all dying ... My poor pigeons are all most dead for want of provisions only 4 remaining out of 16" (Nicholls 1977).

A fortnight later,

> "The distress of the Colony beyond conception meat 3/6 lb. coarse meat 9/– and potatoes 1/6 a pound. Indian corn 7/– a lb. and very bad, and a very little to be obtained. No work to be done, The poor people go out afishing."

Some biscuit came by the *Ferret* on 1 November and was immediately issued: flour 1 lb and biscuit 2 lb to civil, military and free persons and to male prisoners 2 lb biscuit, with the usual proportions to women and children. The crew of the *Ferret* very selfishly tried to prevent this small assistance being given, and the Lieut Governor punished six of them with 200 lashes each for refusing to let land two casks of biscuit and three of flour for the relief of the colony. This lasted for barely a month and the inhabitants were again on short rations: kangaroo and emu were once more received into store — this time at the advanced price of 1/6 per lb.

The new season's wheat crop was a small one. The return of 18 October 1806 showed only 49.5 acres (20 ha) wheat in on Government account and 52 acres (21 ha) between all the settlers. As a result the price was £4 per bushel.

Certain settlers, in fact, combined to raise the price to £6. By general order of 7 February 1807, Collins forbade anyone offering or giving a greater price than £4. This order was quite ineffective. Just a fortnight later Knopwood mentions that

"wheat was not to be obtained at £6 per bushell, and barley £5. Tobacco is also very scarce indeed — Rio tobacco fetching as much as £2/10/– per lb. and sugar very coarse £1 per lb. There was not a piece of lump sugar in the Colony" (Nicholls 1977).

The long-expected cargo of rice from India arrived in the *Duchess of York* on 5 March. She fired a gun at sunrise, and "the whole of the prisoners were so rejoiced that they gave three cheers". The ship brought many other things besides rice. On 7 March, Knopwood records: "a quantity of spirit was landed and almost everybody was drunk" (Nicholls 1977) — the result no doubt of long abstention, and exuberance of joy for the relief of their distress. A further supply of wheat and rice was received from Port Jackson via the *Estremina* shortly afterwards, and the colony was placed on a better ration for a few months. On 29 April, the Lieut Governor sent for the bakers and reduced the price of bread for a fine 2 lb loaf from 5/– to 4/–.

Next month the salt meat in store was too bad to issue and kangaroo had to be resorted to again for a few weeks until a further shipment came from Sydney in the *Elizabeth*. By the beginning of August 1807, the wheat, flour and maize were all spent and there was only rice to issue. The salt meat was also getting scarce, and kangaroo was used to supplement the issue.

Governor Bligh, who had succeeded King as Governor-in-Chief, sent down a supply of meat and maize in the *Porpoise* in October, and this eased the situation somewhat. At the same time he strongly reprimanded Collins for his extravagance in the issue of rations. He pointed out that Collins had issued far too much kangaroo in lieu of other provisions; had paid too high a price for kangaroo and that, in case of want of flour or grain, vegetables and roots are the proper substitutes as the full ration of meat is considered sufficient for any man. Very fine advice to the Lieut Governor who had seen his settlement in dire straits for nearly three years!

On 26 January 1808, Major Johnston deposed Bligh in N.S.W. and from him the subordinate Derwent settlement received better treatment from Sydney. He sent Collins a supply of provisions and assured him that he would continue shipments till he had 12 months stock on hand. Thus ended the disastrous famine.

The reasons for the famine were chiefly three:

(1) Neglect and/or misunderstanding on behalf of the Home Government.

(2) Shipping difficulties. Small ships, delays through weather conditions and loss of stores (e.g. on one occasion when the settlers were practically out of salted meat, of the 60 tierces (casks) loaded, 28 had to be thrown overboard to lighten the ship).

(3) Poor quality of provisions. The provisions Collins brought out from England were generally of excellent quality. This was far from being the case with those received a couple of years later from Port Jackson or from Norfolk Island. Huge quantities of salted meat and flour had to be condemned.

NORFOLK ISLAND SETTLERS

Arriving at the end of the period of famine were some 554 people from Norfolk Island. Many of these were allocated farms on the banks of the Derwent River in the area now called New Norfolk. The grants of land were not as generous as for the first settlers (half in fact), but in other aspects were more liberal (HRA I(6): 73):

"The settlers and other inhabitants are to be divided into three classes —

1st. Discharged Seamen. Marines and old servants of Government who have proved themselves to be industrious and deserving of favour.

2nd. Persons formerly convicts but who have conducted themselves with propriety, or who have large families, or from other causes may have claims to particular attention.

3rd. Comprehend the remainder of inhabitants possessing land or buildings but who have no particular pretensions to the favour of Government.

To all persons in each of these three classes grants of lands (free of expense) on their arrival at Port Dalrymple or Hobart Town (according to their option) to be made in the proportion of two acres for every one of cleared ground, and one acre for every one of waste land possessed at Norfolk Island. Convenient buildings are to be erected on each allotment for the residence of the settlers at the public expense, in the manner hereafter explained, of equal value with the houses which they left behind.

The settlers of the first class and their families to be victualled and clothed for two years: given the labour of four convicts for the first nine months and two for fifteen months longer, victualled and clothed at the public expense.

The second class to be victualled and clothed for two years and be allowed the labour of two convicts for the same period.

TABLE 2
Land Grants

Date	Grantee	Area* (acres)	Locality
A. Initial Land Grants			
15 Aug 1804	Fosbrook, Leonard	100	Near Humphrey's Rivulet
	Bowden, Matthew	100	do.
	Johnson, Lieut J.M.	100	do.
	Miller, Edward	100	do.
18 Dec 1805	Issel, Thomas	100	At Stainforth's Cove
	Hayes, Thomas	100	do.
	Hayes, Henry	100	do.
	Nichols, William	100	do
	Preston, Thomas Richard	100	do.
	Pitt, Richard	100	do.
	Cockerill, William	100	do.
	Blinkworth, John	100	do.
	Dacres,	100	do.
	Littlefield, Thomas Figget	100	do.
	Peters, Mary	40	On the Brook, River Derwent
	Hayes, Martha	50	On Swamp Lagoon, River Derwent
	Sladden, Capt. William	100	At Sandy Bay
1 Jan 1806	Knopwood, Rev. Robert	–	Cottage Green
	Lord, Lieut Edward	100	Adjoining Cottage Green
	Faulkner, -	50	Near the Rivulet
	Littlejohn, Robert	100	At Miller's Bay
	Harris, George Prideaux	100	At Sandy Bay
	Fosbrook, Leonard	14	At Sullivan Cove
	Mansfield, Michael	50	East side of Derwent
	Parish, —	70	do.
	Kelly, Samuel	50	West side of Derwent
	Guest, George	24	At Sullivan Cove
	Clark, Richard	190	do.
	Power, Matthew	50	do.
	Hopkins, Thomas	30	do.
B. Lands granted by Paterson			
9 May 1809	Lord, Lieut Edward	500	River Derwent
12 Sep 1809	Knopwood, Rev. Robert Chaplain at Hobart Town for the time being	400	Clarence Plains do.
	Bader, John	100	do.
	McAskill, Allan	500	River Derwent

* 1 acre = 0.4047 ha

The third class to be victualled and clothed for twelve months and be allowed the labour of two convicts for the same period, and to be in other respects assisted as new settlers.

All classes to be supplied with implements and tools equivalent to those they may have been possessed of and may not have had it in their power to remove.

Stock left behind is to be taken by Government at a fair evaluation and paid for in clothing or other necessaries as the public stores may furnish."

These terms were very generous indeed, *but no attempt was made to enable Lieut Governor Collins to carry them out*, so that there was great dissatisfaction amongst the settlers and constant complaints against the Government. Some, however, agreed to relieve the Government of their obligation to provide buildings for them if they received stock of equal value. The Lieut Governor was able to satisfy them with a few sheep and Bengal cows. The coming of the Norfolk Islanders led to the opening up of more of the country for farming and led to the colony becoming more self-supporting in the matter of food supplies. Thankfully a shipment of 252 Bengal cows arrived in March 1809 (having been ordered in March 1807) from India. These were a great help with the influx of these settlers.

LAND GRANTS AND AGRICULTURE

Collins' commission as Lieut Governor did not empower him to issue land grants, only recommend them. So he issued location orders which entitled the settler to select his land and locate himself upon it. The first schedule of land granted by Governor King is shown in table 2A.

The next list available is of lands granted by Lieut Governor Paterson and is shown in table 2B.

It will be noted that there is no list of grants between 1 January 1806 and 9 May 1809. Many must have been made, especially in view of the large number of settlers who arrived from Norfolk Island in 1808. Many settlers did not bother to procure the official grant, the location orders from the Lieut Governor being deemed sufficient title to their land. Collins made it known that he would not allow applications for grants till the settlers had proved their sincerity and industry.

Some idea of the progress made in agricultural development can be gleaned from table 3, extracted from the few official returns available.

TABLE 3
Agricultural Progress, 1806–09

Date	Wheat	Barley	Acres held	Number					
				Horses	Sheep	Bulls	Cows	Calves	Oxen
Derwent Settlement									
Oct 1806									
Crown	39	–	–	6	282	70	126	–	5
Settlers	64	29	2290	–	436	3	64	–	11
Jul 1807									
Crown	23	13	–	6	301	7	26	115	5
Settlers	77	50	2704	–	747	–	72	62	3
May 1809									
Crown	17	–	–	6	122	2	224	96	–
Settlers	181	56	2979	4	969	4	98	23	42
Port Dalrymple									
Apr 1807									
Crown				2	154	3	229	137	1
Settlers				6	151	2	14	10	–

The return dated May 1809 apparently does not include the Norfolk Island settlers, only those located at New Town being given. Their land would make a considerable increase in the total acreage held, and their labour and stock would swell to a small extent the totals of acres cultivated and stock held.

The colony was beginning to move ahead. There was a steady increase in cultivation, but the methods of agriculture were still crude and unprofitable. Grain was mostly chipped in, leading to poor crops. Continued cropping of the same ground exhausted the soil and resulted in even poorer yields. It is said that some "farmers" were so indolent as to depend upon self-grown grain for a crop. Very few of the early settlers who located themselves at New Town were originally farmers, and lack of knowledge, implements and labourers all combined to prevent them making the best use of their situations. Their gardens contributed largely to their subsistence. Vegetables grew in abundance, especially potatoes, beans and peas. The potatoes were much in demand and the settlers turned large quantities into the Commissariat Store in exchange for articles which they required. Their stock was also on the increase, but here again the bulk of the cows were in the Government herds. Until cattle numbers increased considerably, and were distributed better amongst the settlers, the colony could not hope to be nearly self-supporting in meat.

Sheep do not show the increase from 1806 to 1809 that we would expect. Probably many of them had been slaughtered for food during the time the colony was in want. But a return made on 21 March 1811, gives the number of sheep belonging to "settlers etc" as 1935 and for Port Dalrymple 1638. These are remarkable increases. They proved the suitability of the Tasmanian climate for sheep and gave promise that woolgrowing would become one of the staple industries of the country.

The sheep were of the Teeswater breed (fig. 1), with a slight admixture of the Leicester breed and a few imported from Bengal. But they were very badly managed. It was the custom to run sheep of all ages and sizes together in the same flock, and lambs were allowed to breed before they attained the age of seven months. The wool was of poor quality and not worth anything. It was allowed to rot in heaps on the farms, or was burnt to get rid of it. Sometimes the sheep were not shorn at all. The fact is that the settlers were intent not on producing wool, which was then unsaleable, but meat which they could sell to the Commissariat Store. Under such conditions little improvement in woolgrowing could be looked for. Later Governor King gave Lieut Lord a ram as near the Spanish breed as Government possessed and also sent two for the use of the Government flock "as the amelioration of the wool throughout these colonies is an object much recommended by His Majesty's Government; if it is found your sheep thrive and their wool

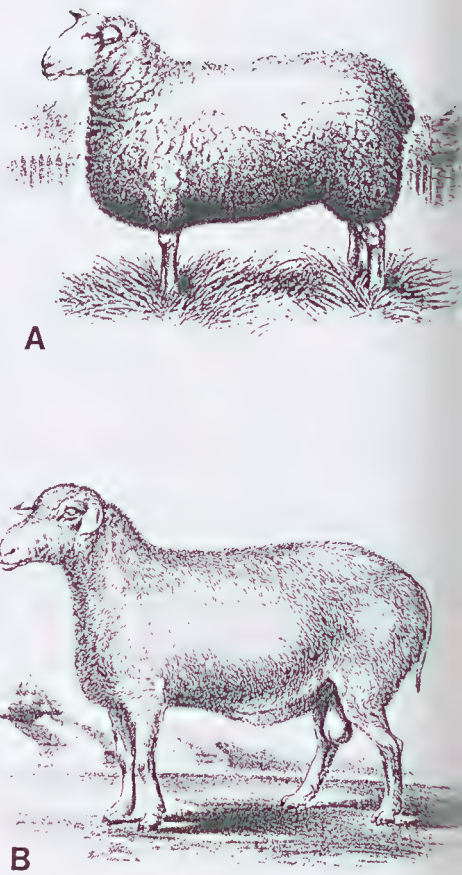

FIG. 1 — Two of the original sheep breeds brought to Tasmania. The Leicester (A) is still to be found in small numbers in Tasmania. Its importance was in the formation of Tasmania's main sheep breed, the Polwarth. The Teeswater (B) is an old English breed not now found in Tasmania.

improves from the rams now sent, it will be desirable you should be furnished with rams nearer the true Spanish breed". It was not until 1820 that Governor Macquarie procured some of MacArthur's best merino rams and sent them to the Derwent to improve the quality of the flocks there.

CONCLUSION

What then were the factors which severely limited growth and development during the period 1803–10? (In fact this situation continued until the early 1820's when Governor Arthur took charge of the colony.)

The limiting factors were:

(a) lack of agricultural expertise,
(b) non-availability of horses and oxen for tilling land,
(c) poor productivity due to poor agricultural methods,
(d) severity of climate,
(e) supply shortages,
(f) abandoning farming in favour of kangaroo hunting which was much easier,
(g) incompetence at all levels,
(h) bribery, corruption, theft, dishonesty, fecklessness —

> "... continually inept and rascally pubic servants and private citizens strove to make money from the government by short changing it and blatantly robbing it blind" ... "If the safety of Van Diemen's Land, like Sodom and Gomorrah, had depended on finding ten honest men it would have been swallowed up in all its iniquity"! (Robson 1983)

(i) aggression of the aborigines,
(j) grubs and smut affecting crops,
(k) drunkenness,
(l) sourness" of the ground,
(m) drought,
(n) labour troubles,
(o) poor quality of tools,
(p) bushrangers, and
(q) sickness — scurvy, diarrhoea and catarrh.

The result was that the new colony was dependent for some time.

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REFERENCES

BARRETT, W.R., 1936: *HISTORY OF TASMANIA TO THE DEATH OF LIEUTENANT-GOVERNOR COLLINS IN 1810*. W.R. Barrett, Hobart.

HRA: *HISTORICAL RECORDS OF AUSTRALIA*. Principally Series III, Vol.1 (1803–12). The Library Committee of the Commonwealth Parliament.

NICHOLLS, M. (Ed.), 1977: *THE DIARY OF THE REVEREND ROBERT KNOPWOOD 1803–1838, FIRST CHAPLAIN OF VAN DIEMEN'S LAND*. Tasmanian Historical Research Association, Hobart.

ROBSON, L., 1983: *A HISTORY OF TASMANIA*. Oxford University Press.

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THE DISTRIBUTION AND TYPE LOCALITY OF *EUCALYPTUS CORDATA* LABILL. — AN HISTORICAL ACCOUNT

by B. M. Potts

(with one table and one text-figure)

POTTS, B.M., 1988 (31:x): The distribution and type locality of *Eucalyptus cordata* Labill. — an historical account. *Pap. Proc. R. Soc. Tasm.*, 122(2): 31–38. ISSN 0080–4703. Department of Botany, University of Tasmania, G.P.O. Box 252C, Hobart, Tasmania, Australia 7001.

The natural distribution of the rare Tasmanian endemic *Eucalyptus cordata* is detailed. Discrepancies with distributional data in the literature are clarified. The type location previously indicated for the species is incorrect and the population initially collected by Labillardière at Adventure Bay in 1793 has been relocated after having eluded the attention of botanists for nearly two centuries.

Key Words: *Eucalyptus*, Tasmania, Labillardière.

INTRODUCTION

Eucalyptus cordata (heart-leaved silver gum) is a regional endemic confined to southeastern Tasmania. It is placed in the informal Subseries Cordatinae (Subgenus *Symphyomyrtus* ; section *Viminales*) by Pryor & Johnson (1971). It is broadly grouped with other endemics such as E. *gunnii*, *E. morrisbyi* and *E. urnigera* as well as with mainland species such as *E. pulverulenta* and *E. cinerea* (Pryor & Johnson 1971). Affinities to *E. urnigera* (Mueller 1880, Brett 1938) and *E. pulverulenta* (Mueller 1880, Baker 1902, Maiden 1913, Hall & Brooker 1972) have been specifically noted. *E. cordata* is planted widely as an ornamental. It is usually homoblastic and the persistent, highly glaucous, cordate juvenile foliage is a distinctive feature of the species (Hall & Brooker 1972).

Eucalyptus cordata is considered a rare and endangered species (Pryor 1981), and during a population study of the species an attempt was made to verify and sample all locations indicated on herbaria sheets (Tasmanian and Melbourne Herbaria; EUCALIST [Nov. 1983] — Chippendale & Wolf 1984), in the taxonomic literature (Rodway 1918, Blakely 1934, Brett 1938, Hall & Brooker 1972) and from current workers. Following this survey, it became apparent that some reports of its distribution required clarification and that the type locality previously indicated for the species (Hooker 1856, Bentham 1867, Baker 1902, Maiden 1913, Hall & Brooker 1972) was incorrect.

DISTRIBUTION

The geographical range of *E. cordata* has been previously indicated by Jackson (1965), Hall & Brooker (1972), Kirkpatrick & Backhouse (1980) and Brown *et al.* (1983). The distribution of all populations verified during the present survey is indicated in figure 1 and population details given in table 1. Twenty-nine separate populations of *E. cordata* have been located, ranging in size from single individuals to a stand of over 5000 individuals (table 1). Its distribution is patchy and disjunct, and the supressed and scattered nature of many of the small, isolated populations is suggestive of a relict distribution pattern. In fact *E. cordata* is probably the remnant of a very early component of the Tasmanian eucalypt flora and its distribution closely follows the limits of Davies' (1974) southeastern glacial refuge. Populations are concentrated in two main geographic areas, viz. the Mt Wellington Range in the west and the general vicinity of Prosser's Sugarloaf in the east, separated by a major lowland disjunction between the Derwent and Coal Rivers. In terms of population size, the main stronghold of the species is clearly the subalpine area around Snug Plain (SP; table 1), although populations in other areas, particularly the Derwent Valley (e.g. Ml and Mo), may have been more extensive prior to agricultural development. Populations occur on Bruny and Maria Islands, both of which would have been continuous with the Tasmanian mainland during glacial periods. However, no populations of *E. cordata* were located south or west of the Huon Valley.

FIG. 1 — The distribution of verified (●) and unverified (○) sites of Eucalyptus cordata. *Population codes are detailed in table 1 (PA = Port Arthur).*

TABLE 1
Location of Populations of *E. cordata*

Location	Code	Universal grid reference		Estimated population size	Adult foliage		Mean height
		E/W	N/S		% of indiv.*	Mean %**	(m)[x]
Perpendicular Mt (top)	Pt	5933	52766	300+	0	0	2.8
Perpendicular Mt (low)	Pl	5930	52765	200	0	0	2.9
Prosser River	PR	5691	52881	6	0	0	1.3
Hellfire Bluff	HF	5766	52683	150	0	0	2.0
Bluestone Tier	BT	5652	52932	55	0	0	1.8
Bream Creek	BC	5687	52614	60	0	0	1.9
Hospital Creek	HC	5673	52660	150	0	0	2.9
Cape Queen Elizabeth	QE	5345	52109	1000	0	0	1.7
Square Mountain	SM	5506	52695	200	0	0	2.7
Electrona	El	5200	52335	110	0	0	5.9
Snug Plain	SP	5120	52317	5000+	0	0	3.2
Falls Hill	FH	5128	52320	30	0	0	3.7
Herringback (top)	Ht	5113	52383	300	0	0	5.1
Herringback (low)	Hl	5119	52385	300	0	0	4.2
Chimney Pot Hill	CP	5225	52476	500	0	0	2.8
Leslie Road	LR	5177	52431	200	0	0	4.8
Combes Hill	CH	5140	52442	800	0	0	5.3
Mt Lloyd	ML	4958	52572	150	30	1.5	7.9
Moogara	Mo	4930	52613	100	10	0.2	15.8
Tarrana	Ta	5714	52319	85	0	0	3.1
Brown Mountain	Bc	5428	52837	150	50	3.8	3.3
Burdons Razorback	BR	5671	52640	1	0	0	–
Combes Hill	CH2	5134	52432	300	0	0	–
Combes Hill	CH3	5136	52438	300	0	0	–
Summerleas Road	SR	5220	52461	10	0	0	–
Chimney Pot Hill 2	CP2	5221	52479	60	0	0	–
Betts Road	Be	5166	52440	2	0	0	–
Penguin Island	Pe	5301	52001	200	40	1.2	4.5
Pony Bottom Creek	PB	5737	52712	40	–	–	–
Meredith Tier[xx]	MT	5763	53301	30	100	93.3	1.9

* Percentage of individuals in the population developing adult or intermediate type foliage.

** Average percentage of reproductively mature foliage expressing the adult or intermediate leaf type.

[x] Average height of the individuals (n=10 in the majority of cases).

[xx] Not *E. cordata*, see Appendix.

TYPE LOCALITY

According to Jackson (1965), *Eucalyptus cordata* occurs south of the Huon Valley, in the Recherche Bay, area and the type locality of *E. cordata* has been cited as Recherche Bay by numerous authors (Hooker 1856, Bentham 1867, Baker 1902, Maiden 1913, Hall & Brooker 1972). However, failure to locate any populations of *E. cordata* in this area, despite extensive searching, prompted a re-assessment of the evidence for the type locality.

Eucalyptus cordata was initially collected by Jacques Julien de Labillardière (1800), the botanist and chief scientist on the French expedition under the command of Bruni D'Entrecasteaux sent in search of the ill-fated La Pérouse expedition by the French Constituent Assembly in 1791. The expedition in the ships *la Recherche* and *l'Espérance* was in Australian waters from 1792 to 1793 and visited Tasmania twice during this period (see Maiden 1910, Hogg 1938, Stafleu 1966, Carr & Carr 1976). E. *cordata* was described and illustrated in Labillardière's work on the botany of the voyage, *Novae Hollandiae Plantarum Specimen* in 1806. The locality for E. *cordata* was given as "capite van-Dieman"; the general locality given for all of his Tasmanian collections (Kantvilas 1983). *E. cordata* was later collected by Joseph Hooker and Ronald Gunn from the "Huon district" (Hooker 1856) and, in part 3 of his *Botany of the Antartic Voyage*, Hooker (1856) indicated Labillardière's locality for E. *cordata* to be Recherche Bay. In his *Eucalyptographia*, von Mueller (1880) listed several collectors who located *E. cordata* in the same region as Labillardière (Brown, Hooker, Gunn, Stephens and Abbott), yet Maiden (1913) could find no evidence for this statement.

In a letter to Sir William Hooker, the father of Joseph Hooker, Gunn wrote of an excursion to Recherche Bay in 1838 which enabled him to identify nearly all of Labillardière's Tasmanian species (Dec. 1843, letter 184, Burns & Skemp 1961). In the same paragraph he mentions *E. cordata*, although no clear indication is given as to whether or not he located this species in the area. There is a specimen of *E. cordata* attributed to Gunn at Kew with the locality given as Recherche Bay, although the specific code given (No. 1207) does not correspond to Gunn's code for *E. cordata* (No. 1071). This specimen has been inspected and is clearly *E. cordata* with the morphology similar to that found in the western populations of *E. cordata*. However, the specimen is not annotated in Gunn's handwriting, is undated and does not have one of Gunn's coded collecting labels which is atypical for Gunn's specimens. This specimen is on the same herbarium sheet as a specimen collected by Gunn from near the Huon River (30/10/1839) and may have originated from this collecting trip. Furthermore, in discussing Labillardière's collections in later correspondence (letter 185, Burns & Skemp 1961) Gunn noted "Eu*calyptus cordata* [Lab.] t.152. Is my own No 1071 — a species I never saw except in the Country South of Hobart Town." Where Gunn located species at Recherche Bay, this was clearly indicated in the letter and the latter comment probably refers to the area immediately south of Hobart.

The specimens sent to Baron von Mueller by Abbott (MEL104507 and MEL104504) were from Huon Road (North West Bay). However, there is one specimen sent to him by T. Stephens from Recherche Bay (MEL104502 — left specimen). At the time, with von Mueller preparing his *Eucalyptographia*, there was considerable interest in this "rare species" and the belief that Recherche Bay was the type locality was widely held (Stephens 1882, 1889) —

> "..... this interesting tree, discovered and described long ago, had been lost to sight for more than forty years. It was originally reported as a denizen of Recherche Bay by the French expedition under Labillardière ; and long afterwards, in Sir John Franklin's time, it was found by Sir Joseph Hooker and the late Mr. Ronald Gunn 'in the Huon district', no precise locality having been recorded. From that time to the present it appears to have eluded the search of botanists ; and it was only in October last that, in answer to repeated enquires, specimens were at last obtained from Recherche Bay, but without flower or fruit." (Stephens 1882).

The letter accompanying the specimen read —

> "Eucalyptus *cordata* is found at last. ... I received from Recherche Bay a branchlet of a young *Eucalyptus*, and this was followed by a letter from the finder stating that there was no blossom or any sign of fruit on any of the trees near" (Stephens to von Mueller, Nov. 1880).

Inspection of this specimen suggests that it is probably not *E. cordata*, but more likely a juvenile of *E. globulus*, which would accord with the noted absence of reproductive material. The juvenile foliage of *E. globulus* resembles the adult foliage of the western populations of *E. cordata*.

The belief that Recherche Bay was the type locality no doubt stemmed from Hooker's (1856) original citation, although he gave this locality for

many of Labillardière's "capite van-Diemen" locations. Labillardière was based and collected extensively in the vicinity of Recherche Bay. He recorded collecting several species of eucalypts on the shore to the northeast of their anchorage on 23 April 1792, but no distiguishing remarks on the species collected were given (Labillardière 1800). He later (6 May 1792) recorded specifically collecting *E. globulus* by felling a tree in order to obtain flowers, and designated the name for the species in his journal. However, he also collected from other areas along the D'Entrecasteaux Channel, including Bruny Island (Townrow 1978) and it is always possible he may have made multiple, unrecorded collections of single species.

Bentham (1867, vol. 3, p. 224) ascribed a specimen of Labillardière's, without flower or fruit, collected from Maria Island, to the mainland species, *E. macrocarpa*. In reference to this, Maiden (1913, p. 241) later noted "Maria Island is off the coast of Tasmania, and I suggest that Labillardière's specimen is E. cor*data*, Labill." Labillardière did not collect on Maria Island, although collections from Maria Island were made later by Leschenault de la Tour, the botanist on the French expedition (1800-1804) commanded by Nicholas Baudin (Péron 1975). Specimens from the Baudin expedition were not described as a whole, but examined from time to time by monographers (Maiden 1910).

There is strong evidence that Labillardière accessed this collection and used some specimens in his *Novae Hollandiae Plantarum Specimen*, mislabelling the localities (Nelson 1974, 1975; Carr & Carr 1976). The herbarium specimen ascribed to Labillardière by Bentham has not yet been located. However, it is possible that a specimen of E. *cordata* was collected from the summit of Perpendicular Mountain during the Baudin expedition and has been both misidentified and mistakenly attributed to Labillardière. Nevertheless, this is not a cause of confusion and there is no doubt that Labillardière personally collected *E. cordata*.

Recent findings have revealed that Recherche Bay is not the type locality of *E. cordata*, and it follows there is no solid evidence for its occurrence in the area. In "Relation du Voyage de la Recherche de la Pérouse", Labillardière specifically recorded collecting a eucalypt from Penguin Island while the expedition was anchored in Adventure Bay, just prior to the final departure from Tasmania. This island had been previously charted and is clearly named on charts from Captain James Cook's 1777 expedition (Triebel & Batt 1957). Labillardière's (1800: 76) description leaves no doubt this eucalypt is *E. cordata* —

> "Je recueillis sur l'île aux Pinguins ..... ; un *eucalyptus* de hauteur médiocre, qu'on reconnoîtra facilement à ses feuilles opposées, sessiles et glauques;...."

The translation of *glauque* (glaucous) in the English version of his journal (1800) "... opposite, sessile leaves, of a whitish green colour, with a slight tint of blue.." is not as botanically exact as the original, and similar, but more severe problems with the translated version have been detailed by Carr & Carr (1976).

The occurrence of E. cor*data* on Penguin Island has recently been verified (14 August 1987) after having escaped the notice of botanists for nearly two centuries. The small island is dominated by *Casuarina stricta* low forest, with some *E. globulus* on the northern aspect, most of which has been recently burnt (March 1986). However, *E. cordata* occurs on the wetter, southern cliff slope which faces Fluted Cape and the majority of the population is unburnt. The population is small, comprising approximately 200 mature individuals, and cannot be missed when following the narrow ridge to the summit of the island, the path presumably taken by Labillardière in 1793. A few individuals are readily accessible from the main ridge suggesting that the type locality can be predicted to within less than 30 m. It is even possible that the same individuals have been sampled in the present survey.

Labillardière's holotype (FI, Herb. Webbianum) and isotypes (MEL104513; G; P) of *E. cordata* are consistent with specimens collected from Penguin Island. Moreover, this population is somewhat atypical for *E. cordata* as approximately 40% of reproductively mature individuals had developed a very small proportion (<5%) of adult or intermediate foliage. Such individuals are usually rare in natural populations of *E. cordata* (table 1). The opposite and glaucous juvenile type of foliage is usually fully retained throughout the life of an individual, although intermediate or adult leaves may occasionally be seen at the top of large trees (Hall & Brooker 1972). Nevertheless, Maiden (1919) noted

> "... *E. cordata* is one of the few remaining species with homoblastic leaves ... I would invite the further attention of collectors to this tree, in order that they may search, especially near the tops, both cultivated specimens, and trees in their native habitats, for pedicellate, lanceolate leaves. The nearest I have got to this state is in a

specimen (2c of Plate 84 C.R.) collected by Labillardière himself."

It is possible *E. cordata* was also observed during Cook's 1777 visit to Adventure Bay, as a recently published sketch by William Ellis from this expedition may feature *E. cordata* (Joppien & Smith 1987). Professor W. D. Jackson (on p.630) suggested plants in the foreground of the sketch, on the shore, may be wither juvenile *E. globulus* or *E. cordata*. His observations were made prior to the rediscovery of *E. cordata* on Penguin Island. The island is in the immediate vicinity of Cook's anchorage and is the only area known today where *E. cordata* grows near sea level. In fact the leaf shape, tree form and even the possible adult foliage on one of the top branches, specifically noted by Prof. Jackson, are more consistent with the *E. cordata* in this area than juvenile *E. globulus*.

Specific records of collection can be obtained for some of the 265 specimens described in *Novae Hollandiae Plantarum Specimen* from Labillardière's journal (Labillardière 1800). Along with the example of E. *cornuta* Labill., described by Carr & Carr (1976), the present case attests to the accuracy and detail of his account. Furthermore, due to the limited size of the *E. cordata* population on Penguin Island, the re-location of this type locality may be one of the most exact from this early period of botanical exploration in Australia. In other cases, specific predictions of Labillardière's type localities have been made by integrating population phenological and distributional data with excursion and anchorage records (e.g. Stipa — Townrow 1978). All of the other Tasmanian eucalypts collected and described by Labillardière (1806), viz. *E. ovata* Labill., *E. viminali*. Labill., *E. globulus* Labill. and *E. amygdalina* Labill., are widespread through the areas Labillardière visited (e.g. Kirkpatrick & Backhouse 1980). Specific mention is only made of *E. globulus*, although his numerous references to *E. resinifera* no doubt refer to *E. obliqua*; a species widespread in Tasmania and common in the vicinity of Recherche Bay. When describing *E. ovata*, Labillardière (1806) gave the locality as "terra van-Leuwin" (Western Australia), the only other area in Australia in which he collected. *E. ovata* is confined to southeastern Australia, including Tasmania, and this is one of the species used by Nelson (1974, 1975) to demonstrate that Labillardière accessed other collections as well as confused some of his own collecting localities in specimens described in *Novae Hollandiae Plantarum Specimen*. Nevertheless, many of the location anomalies and other problems associated with Labillardière's works have now been resolved (Nelson 1974, 1975, Carr & Carr 1976), and Carr & Carr (1976) considered that many errors of interpretation could have been avoided with greater collaboration between botanists and historians.

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REFERENCES

BAKER, R. T., 1902: On *Eucalyptus cordata*, Labill., and its cognate species. *Aust. Assoc. Adv. of Sci.* IX: 344–348.

BENTHAM, G., 1867: *FLORA AUSTRALIENSIS: A DESCRIPTION OF THE PLANTS OF THE AUSTRALIAN TERRITORY*. Lovell Reeve & Co., London.

BLAKELY, W. F., 1934: *A KEY TO THE EUCALYPTS*. The Workers Trustees, Sydney.

BRETT, R. C., 1938: A survey of Eucalyptus species in Tasmania. *Pap. Proc.R. Soc. Tasm.* (1937): 75–111.

BROWN, M.J., KIRKPATRICK, J. B. & MOSCAL, A., 1983: *AN ATLAS OF TASMANIA'S ENDEMIC FLORA*. The Tasmanian Conservation Trust Inc., Hobart.

BURNS, T. E. & SKEMP, J. R., 1961: *VAN DIEMEN'S LAND CORRESPONDENTS*. Queen Victoria Museum, Launceston.

CARR, S. G. M. & CARR, D. J., 1976: The French contribution to the discovery of Australia and its flora. *Endeavour* 35 (124): 21–26.

CHIPPENDALE, G. M. & WOLF, L. J., 1984: EUCALIST: Computerized Data Retrieval System for *Eucalytpus* (Myrtaceae). *Aust. For. Res.* 14: 147–152.

DAVIES, J. L. 1974: Quaternary Environments. *In* Williams, W.D. (Ed.): *BIOGEOGRAPHY AND ECOLOGY IN TASMANIA*. W. Junk, The Hague: 17–27.

HALL, N. & BROOKER, I., 1972: Heart-leaved Silver Gum: *Eucalyptus cordata* Labill. Forest Tree Series No. 53. A.G.P.S., Canberra.

HOGG, G. H., 1938: D'Entrecasteaux: An account of his life, his expedition, and his officers. *Pap. Proc. R. Soc. Tasm.* (1937): 53–74.

HOOKER, J. D., 1856: *THE BOTANY OF THE ANTARCTIC VOYAGE. PART 3. FLORA TASMANIAE.* Lovell Reeve, London.

JACKSON, W. D., 1965: Vegetation. *In* Davies, J. L.(Ed.): *ATLAS OF TASMANIA.* Lands and Mercury Press, Hobart: 30–34.

JOPPIEN, R. & SMITH, B. 1987: *THE ART OF CAPTAIN COOK'S VOYAGES: THE VOYAGE OF THE RESOLUTION AND DISCOVERY 1776–1780.* Vol.3, Oxford University Press, Melbourne: plate ii.

KANTVILAS, G., 1983: A brief history of lichenology in Tasmania. *Pap. Proc. R. Soc. Tasm.* 117: 41–51.

KIRKPATRICK, J. B. & BACKHOUSE, S., 1980: *ILLUSTRATED GUIDE TO TASMANIAN NATIVE TREES.* Mercury-Walch, Hobart.

LABILLARDIÈRE, J. J., 1800: *RELATION DU VOYAGE À LA RECHERCHE DE LA PÉROUSE.* Paris.

LABILLARDIÈRE, J. J., 1804–1807: *NOVAE HOLLANDIAE PLANTARUM SPECIMEN.* Vol. 11. Paris.

MAIDEN, J. M., 1910: Records of the earlier French Botanists as regards Australian plants. *J. R. Soc. N.S.W.* 44: 123–155.

MAIDEN, J. M., 1913: *A CRITICAL REVISION OF THE GENUS* EUCALYPTUS. Vol. 2. Government Printer, Sydney. : pts 17–19.

MAIDEN, J.M., 1919: Notes on Tasmanian eucalypts. *J. R. Soc. N.S.W.* 53: 82–90.

NELSON, E. C., 1974: The locations of collection and collectors of specimens described by Labillardière in "Novae Hollandiae Plantarum Specimen": additional notes. *Pap. Proc. R. Soc. Tasm.* 108: 159–170.

NELSON, E. C., 1975: The collectors and type locations of some of Labillardière's "Terra Van-Leuwin" (Western Australia) specimens. *Taxon* 24: 319–336.

PÉRON, M.F., 1975: A *VOYAGE OF DISCOVERY TO THE SOUTHERN HEMISPHERE.* Marsh Walsh Publishing, North Melbourne.

PRYOR, L. D., 1981: *AUSTRALIAN ENDANGERED SPECIES : EUCALYPTS.* Spec. Publ. 5. Aust. Nat. Pks Wildl. Serv.

PRYOR, L. D. & JOHNSON, L.A.S., 1971: *A CLASSIFICATION OF THE EUCALYPTS.* A.N.U. Press, Canberra.

RODWAY, L., 1918: Tasmanian eucalypts. *Pap. Proc. R. Soc. Tasm.* (1917): 10–20.

STAFLEU, F. A., 1966: Introduction to facsimile edition of Novae Hollandiae Plantarum Specimen (Labillardière 1804), Historiae Naturalis Classica, Weinheim.

STEPHENS, T., 1882: Note 27. Specimen of Eucalyptus cordata. *Pap. Proc. R. Soc. Tasm.* (1881): iv.

STEPHENS, T., 1889: Notes and Exhibits. *Pap. Proc. R. Soc. Tasm.* (1888): xxxiii.

TOWNROW, J. E. S., 1978: Stipa L. in Tasmania — historical notes: Taxonomic contributions 1768–1968 and the type locality of Stipa flavescens Labill. Pap. Proc. R. Soc. Tasm. 112: 215–226.

TRIEBEL, L. A. & BATT, J. C., 1957: *FRENCH EXPLORATION OF AUSTRALIA WITH SPECIAL REFERENCE TO TASMANIA.* Tasmanian Government Printer, Hobart.

VON MUELLER, F., 1880: *EUCALYPTOGRAPHIA. ATLAS OF THE EUCALYPTS OF AUSTRALIA AND THE ADJOINING ISLAND.* Trubner and Co., London.

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APPENDIX

Additional notes

Several additional anomolous records of *E. cordata* were found which require further comment.

Meredith Tier (MT)

The northernmost population indicated in Brown *et al.* (1983) on Meredith Tier (MT) was not included within *E. cordata* and its exact affinities require further investigation. When this population was originally located by F. Duncan, it was regenerating from wildfire and the original specimen collected bore capsules in the juvenile foliage stage. However, when sampled several years later, all reproductively mature individuals had developed adult foliage. The exact affinities of this population are masked by what appears to be extensive hybridisation with the nearby *E. barberi*. This population is within the climatic range of *E. cordata* as predicted using the climatic model BIOCLIM (Potts & Minchin, unpubl. data). However, the closest and northernmost stand of *E. cordata* is on Bluestone Tier (BT) which is over 40 km south of this site. The population on Meredith Tier may have closer affinities to *E. gunnii*, the nearest population of which occurs only 7 km away, near Tooms Lake.

Brown Mountain, Port Arthur (PA)

The Port Arthur and Brown Mountain locations noted by Brett (1938) and Rodway (1918) respectively correspond to herbarium specimens (HO 15629–32, 15637–39, 15660–62, 16077) they independently collected from Brown Mountain near Port Arthur. This population was not relocated despite extensive searching. Some of Rodway's specimens (initially labelled *E. globulus* var. Harrisoni e.g. HO 16077) from this location were noted as collected from tall trees (33–66 m), whereas the vegetation in this specific area is low mallee and no stands could be found in taller, wetter forests nearby. Brett's specimen from the same location is annotated as being an *E. globulus* x *cordata* hybrid and that the *E. cordata* in the area was an undershrub growing in association with *E. globulus*. Intermediate or adult foliage occurs on some of these specimens. In this respect, the resemblance between some of the specimens collected by Rodway and Brett from Brown Mountain and those from the type locality is noteworthy and may account for Brett's (1938) record of hybridisation between *E. globulus* and *E. cordata*.

Brown Mountain, Campania (Bc)

The Brown Mountain (Bc) sampled in the present survey occurs near Campania and is no doubt the Brown Mountain and Campania locations given by Brett (1938) and Rodway (1918) respectively. Brett's Port Arthur locality probably corresponds to his specimens from the Brown Mountain near Port Arthur. While individuals developing intermediate type foliage were found in the population on Brown Mountain near Campania (table 1), this mountain is unlikely to have been confused with the locality collected by Rodway or Brett from near Port Arthur (PA; see above). The population near Campania is low mallee, there is no *E. globulus* in the vicinity and the specimens do not correspond to samples collected from this population. The population (Bc) showed some affinities to *E. urnigera* in capsule shape and juvenile leaf shape, but the majority of individuals developed flowers in the juvenile leaf stage. While this stage is not fully persistent (table 1), it has been included within *E. cordata* for the present survey. In this respect it is significant that Brett (1938) indicated *E. cordata* had affinities to *E. urnigera* and von Mueller (1880) noted:

> "Crenulate leaves occur also in *E. urnigera*, and, strange as it may appear, it is to this species that *E. cordata* bears the closest alliance; for although the aged state of *E. urnigera* has scattered long-stalked dark- green and lanceolar-sickleshaped leaves, more slender elongated and downward more attenuated calyces on conspicuous stalklets with ampler lid and urnshaped fruits with deeply enclosed valves, yet trees are now known (through Mr. Stephens from "Old Man's Head", a subalpine mountain near Lake Cresent) [no doubt Alma Tier], which to all appearance form a complete transit from *E. urnigera* to *E. cordata*. Moreover Mr. Aug. Oldfield sent many years ago from the middle-regions of Mount Wellington sterile saplings as the young state of *E. urnigera*, the adventitious lower shoots of which can in no way be distinguished in foliage from *E. cordata* and which are also partly pruinous. On the summit of Mount Wellington I collected a state of *E. urnigera*, with all leaves nearly oval and with simply truncate-ovate fruits."

Nelson's Tier

The Nelson's Tier location noted by several authors (Stephens 1889, Blakely 1934, Brett 1938) probably corresponds to the population sampled on the contiguous Square Mountain (SM), although the possibility of other populations in this general locality can not be discounted.

Fisherman's Island

The present day locality of Abbott's specimen collected in 1881 (MEL104503) and labelled "Fisherman's Island" is unclear. This specimen corresponds to the morphology found in the western populations and does not correspond to samples from Maria (Pt, Pl) or Bruny (QE, Pe) Islands.

LEAF LITTER IN TWO SOUTHERN TASMANIAN CREEKS AND ITS RELEVANCE TO PALAEOBOTANY

by R. J. Carpenter and P. Horwitz

(with one table and one text-figure)

CARPENTER, R. J. & HORWITZ, P., 1988 (31:x): Leaf litter in two southern Tasmanian creeks and its relevance to palaeobotany. P*ap. Proc. R. Soc. Tasm.* 122(2): 39–45. ISSN 0080–4703. Botany Department (R.J.C.) and Centre for Environmental Studies (P.H.), University of Tasmania, G.P.O. Box 252C, Hobart, Australia 7001.

Benthic and drifting leaf litter were examined in two parallel creeks in mixed forest in southern Tasmania, and the occurrence of whole leaves recorded. Nothofagus *cunninghamii* leaves were dominant in both the benthic and drift samples, *Atherosperma moschatum* occurred in the drift but only in trace quantities in the benthic samples, *Phyllocladus aspleniifolius* occurred in the benthos but only in trace quantities in the drift samples, and whole *Eucalyptus obliqua* leaves were absent from all samples. Otherwise most species occurred in similar proportions in both creeks and for both sampling strategies. It is concluded that the processes of litter input, leaf buoyancy, and leaf breakdown will result in an unequal potential for fossilisation of the leaves of different species; accordingly, attempts to reconstruct vegetation using macrofossils need to be approached with caution.
Key Words: leaf litter, mixed forest, creek benthos, drift, southern Tasmania, palaeobotany.

INTRODUCTION

Variations in the relative proportions of the leaves of different species represented as leaf litter at surface and benthic levels in lotic and lentic systems, when compared to the surrounding vegetation, may have important implications for both palaeobotanical and limnological research.

Leaves may reach a freshwater system by falling in directly from overhanging vegetation, being blown in (usually from nearby canopy trees) or washed from the litter of the forest floor. The number of whole leaves reaching the water will be dependent upon the amount of litter produced by each species, their size, shape and density, and their susceptibility to mechanical and biological breakdown. Furthermore, buoyancy of the leaves of different species varies so that some may be carried relatively long distances by wind and current whereas others, such as *Eucalyptus coccifera*, fall directly and sink rapidly (Hill & Gibson 1986a). Leaf breakdown may commence with the leaching of water soluble substances followed by invasion of the leaf by micro-organisms, which in turn may be grazed by invertebrates. It is therefore likely that the macrofossil record will be biased towards plants with resistant leaves growing along watercourses. Many of these factors have been discussed by Ferguson (1985) and Birks & Birks (1980).

Little information regarding the input of potential macrofossils into southern hemisphere freshwater systems exists, while even less is known of the feeding ecology of rainforest stream invertebrates (Bunn 1986), and how this may effect the longevity of leaves in the system. The study by Hills & Gibson (1986a) of the distribution of potential macrofossils in Lake Dobson, Tasmania related particularly to subalpine woodland dominated by *Nothofagus cunninghamii* and Epacridaceae/Proteaceae sclerophyll vegetation and not to common Tasmanian cool temperate rainforest elements such as *Atherosperma moschatum* (sassafras), *Eucryphia lucida* (leatherwood) and *Phyllocladus aspleniifolius* (celery-top pine).

Nothofagus leaves with affinity to *N. cunninghamii* and *N. moorei* are abundant in Tasmanian Tertiary deposits (Hill 1983, Hill 1984, Hill & Macphail 1983, Hill & Gibson 1986b) and *Phyllocladus* cladodes have been found in several deposits (Hill & Macphail 1983, 1985). However, other rainforest taxa such as *Atherosperma* (Monimiaceae), *Eucryphia* (Eucryphiaceae), *Anopterus* (Escalloniaceae) and *Aristotelia* (Elaeocarpaceae) have a meagre Tertiary

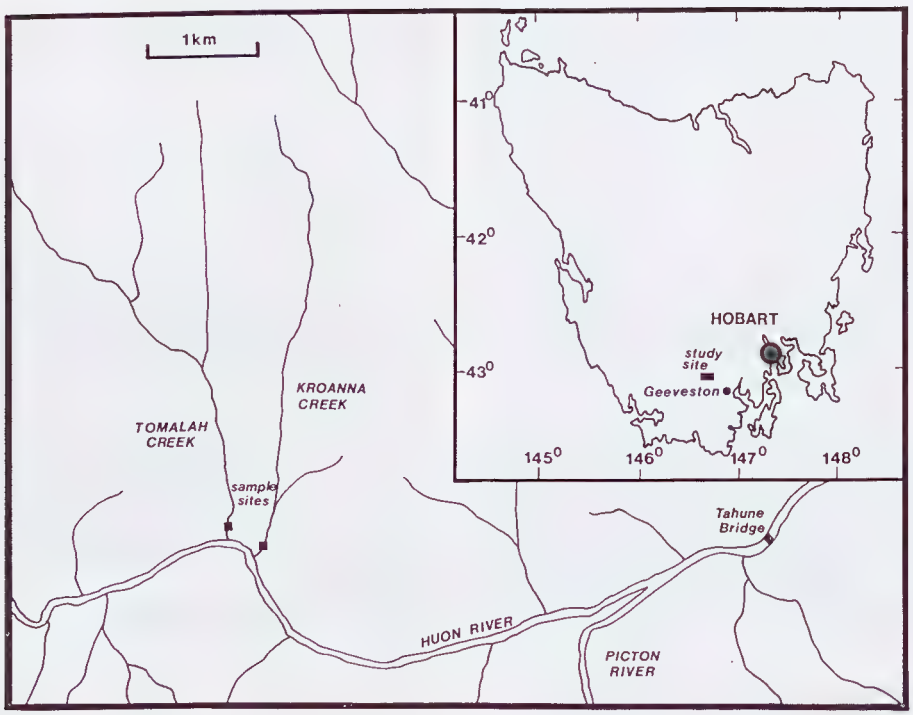

FIG. 1 — The locations of the study sites. For details see Huon 1:100 000 Sheet 8211 (second edition).

macrofossil record despite being considered to have undoubted Gondwanic ancestry (e.g. Raven & Axelrod 1972, Barlow 1981, Jarman & Brown 1983). Tertiary leaves of *Eucryphia* and *Atherosperma* have been documented only from the Regatta Point Plio-Pleistocene deposit (Hill & Macphail 1985). Furthermore, taxa typical of Tasmanian mixed and wet forest such as *Eucalyptus*, *Olearia*, *Phebalium* and *Pomaderris* have no confirmed Tasmanian Tertiary macrofossil record despite being common components of the extant vegetation. A single fossil *Acacia* phyllode is known only from Regatta Point, but is distinct from extant Tasmanian species (Hill & Macphail 1985).

The aim of the present study was to identify the proportionate species composition of whole leaf litter in southern Tasmanian streams which flow through mixed forest, and to determine whether these proportions are altered by using different methods of *in situ* collection. In doing so, we hoped to gain some insights into the potential of leaves of the above taxa to become fossilised, and to relate this information to their relative representation in the Tasmanian fossil record.

METHODS AND MATERIALS

Two permanent streams were selected; Tomalah Creek and Kroanna Creek. Each flows into the Huon River (at approximately 80 m a.s.l.) 4–5 km upstream from Tahune Bridge, near Geeveston, southern Tasmania (fig. 1). Sampling was conducted at sites approximately 30 m upstream of the confluence between each stream and the Huon River. As the streams flow closely parallel to each other, the two sampling sites were no more than 400 m apart. The present study was undertaken during an investigation of drifting invertebrate fauna and the effects of logging activity on this fauna (conducted by the Tasmanian Inland Fisheries Commission).

The streams flow over Permian marine mudstone and the bed loads of the streams consist predominantly of rocks between 0.03 and 0.15 m in diameter.

Kroanna Creek is approximately 0.5–1 m wide at basal flows and at the same levels Tomalah Creek is approximately 1–2 m in width. Whereas the hydrologies of the two streams are essentially similar with respect to temperature regimes, pH,

turbidity and conductivity (R. King, pers. comm. 1987), Kroanna Creek carries approximately half the water of Tomalah Creek.

The composition and abundance of plant species in the surrounding vegetation between the creeks was observed and is best described as mixed forest with eucalypts being the major canopy trees. Wet sclerophyll species such as *Eucalyptus obliqua*, *Pomaderris apetala*, and *Phebalium squameum* dominate the better drained sites with an understorey of plants including *Coprosma quadrifida*, *Cyathodes glauca*, and *Polystichum proliferum*. Rainforest species such as *Nothofagus cunninghamii*, *Eucryphia lucida*, *Anopterus glandulosus* and *Atherosperma moschatum* become more prevalent in the creek gullies. Three *Acacia* species were recorded. *Dicksonia antarctica* was common along both streams.

Two sampling techniques were used in this study; one to examine the benthos and one to examine drift. At each site ten benthic samples were taken using a modified Surber sampler (see Winterbourn 1985); such nets are one of a number of standard techniques for sampling the benthic invertebrates of freshwater systems. For each sample an area of 0.1 m^2 was enclosed and the substratum was manually disturbed to a depth of 50–100 mm. This disturbance throws material such as benthic invertebrates, plant matter (coarse particulate organic matter — CPOM), and substrate into the water column to be carried into the net of 500 µm mesh.

The drift of each creek was sampled by using a drift net, of mesh 500 µm, which enclosed an area of 0.1 m^2. The nets were fixed into place perpendicular to the water flow in riffle sections of the creek and material drifting downstream over a 24–hour period was collected. The nets sampled the entire depth of the creeks. On the 8 and 9 October 1986 four 24-hour drift samples were collected from Tomalah Creek and two 24-hour drift samples from Kroanna Creek. No significant rainfalls had occurred immediately prior to the sampling period (thus sampling was not connected during a spate).

All samples were preserved immediately in 5–10% formaldehyde solution and later stored in 70% alcohol to await sorting. Each sample was then passed through a 2 mm sieve to retain CPOM. Whole leaves, defined as possesing both base and apex, were identified to species level and tallied. The presence of identifiable leaf fragments was recorded as supplementary information. Only whole leaf data were quantified since we consider that whole leaves would be more likely to be identified in palaeobotanical studies. It is therefore to be expected that some bias towards smaller leaves will occur since large leaves will be more susceptible to mechanical fragmentation in the creeks.

RESULTS

All samples were sorted individually (as above) but combined to give both the number and proportion (expressed as a percentage) of each species found in either the benthos or the drift of each creek (table 1). The combination of samples allowed for easier comparisons and analyses and was made possible by the high degree of replicability between each related sample.

With few exceptions (see discussion) the species representation in the litter of the creeks was a good reflection of the nearby vegetation along the creeks.

In general the results from the two creeks were similar. In the benthic samples *Nothofagus cunninghamii* was by far the most commonly occurring species, with an average abundance of 73% in Tomalah Creek and 80% in Kroanna Creek. The major difference between the two creeks was the amount of *Acacia verticillata*; in Kroanna Creek it was the second most common species with 10%, whilst in Tomalah Creek it was found in only trace quantities and *Eucryphia lucida* was subdominant with 19%. *Phyllocladus aspleniifolius* and *Acacia melanoxylon* were present in minor proportions in both creeks. The remaining species occurred only in trace quantities.

In the drift samples *N. cunninghamii* was also the dominant species with 60% in Tomalah Creek and 51% in Kroanna Creek. Similar to the results for benthic samples, drifting whole leaves of *Acacia verticillata* were abundant (33%) in Kroanna Creek but were absent from Tomalah Creek. Trees of this species overhang Kroanna Creek and produce abundant small phyllodes. In Tomalah Creek *Atherosperma moschatum* and *Eucryphia lucida* were present in high proportions in the drift whilst the small leaves of *Coprosma quadrifida* and *Leptospermum lanigerum* were present in low numbers and the six other species were found in only trace quantities. In Kroanna Creek *Atherosperma moschatum*, *Eucryphia lucida*, *Acacia melanoxylon*, *Phebalium squameum* and *Coprosma quadrifida* were present in low numbers and four other species occurred in trace proportions. Frond fragments of the tree fern *Dicksonia antarctica* were common and identified

TABLE 1
Composition of Leaf Litter: the Number* and Percentage for Each Species in Each of the Two Creeks

Species	Benthos		Drift	
	Tomalah	Kroanna	Tomalah	Kroanna
Nothofagus cunninghamii	673 (73)	390 (80)	358 (60)	99 (51)
Eucryphia lucida	174 (19)	17 (4)	83 (14)	9 (5)
Acacia verticillata	1 (trace)	49 (10)	–	64 (32)
Atherosperma moschatum	5 (trace)	4 (trace)	133 (22)	7 (4)
Acacia melanoxylon	43 (5)	12 (2)	1 (trace)	5 (3)
Phyllocladus aspleniifolius	17 (2)	10 (2)	1 (trace)	–
Pomaderris apetala	8 (trace)	1 (trace)	3 (trace)	1 (trace)
Phebalium squameum	–	4 (trace)	–	4 (2)
Coprosma quadrifida	–	–	10 (2)	4 (2)
Aristotelia peduncularis	–	–	3 (trace)	–
Prionotes cerinthoides	3 (trace)	–	1 (trace)	–
Monotoca glauca	–	–	1 (trace)	–
Leptospermum lanigerum	2 (trace)	–	8 (1)	1 (trace)
Anopterus glandulosus	–	–	–	1 (trace)
Trochocarpa sp.	–	1 (trace)	–	1 (trace)
Olearia persoonioides	1 (trace)	–	–	–
Totals	927	488	602	196

* Whole leaves only.

in every sample from both creeks. *Acacia dealbata* pinnae were common in Tomalah Creek. Species which were only rarely recorded as large foliage fragments were *Eucalyptus obliqua*, *Olearia argophylla*, *Orites diversifolia*, *Blechnum nudum* and *B. wattsii*. With the exception of *E. obliqua* these species were uncommon in the regional vegetation.

A total of 2213 whole leaves were counted representing 16 species. An additional seven species were found as large leaf, phyllode or frond fragments only (as above), bringing the total to 23 species in the leaf litter of the two streams.

DISCUSSION

The techniques of benthic and drift sampling, usually reserved for the analysis of freshwater invertebrates, have shown some interesting differences between the behaviour of leaves in lotic systems.

Nothofagus cunninghamii leaves were dominant in all samples whereas leaves of the major canopy tree in the area, *Eucalyptus obliqua*, were only recorded as rare, incomplete fragments. *Nothofagus* leaves are small and coriaceous whereas fallen eucalypt leaves are apparently poorly dispersed (Hill & Gibson 1986a) and seem more susceptible to breakdown. Other researchers have also noted a relatively rapid decomposition of eucalypt leaves. For instance, O'Keefe & Lake (1987) found that the consumption of eucalypt leaves by invertebrates began almost as soon as they were placed in a study stream in southern Victoria. The difference in abundance between *Nothofagus* and *Eucalyptus* leaves may also be due to the fact that *N. cunninghamii* trees were relatively more abundant in the moister, shadier creek gullies whereas the eucalypts were usually found in drier locations. Thus in a mixed forest such as this, it can be expected that rainforest species close to the creek are likely to contribute a larger proportion of leaf litter to the creek than *Eucalyptus* spp. and other plants of drier habitats. In order to provide some additional data with which to assess this idea, in May 1987 a transect was constructed perpendicular to each creek, and leaf

litter was collected and tallied from 1 m^2 plots at 5 m intervals up to 25 m. In all over 2500 leaves were tallied. The results were generally as expected. For instance, near Kroanna Creek *N. cunninghamii* leaves decreased from being the most commonly collected neat to the creek until they comprised only 3% of the total leaf litter at 25 m from the creek, whereas *E. obliqua* leaves were low in number and proportion (about 1%) next to the creek and increased to 11% at 25 m. *Atherosperma moschatum* leaves were very common (about 20%) close to the creek but were absent at 25 m. *Eucryphia lucida* and *Pomaderris apetala* leaves were common along transects; the former especially near the creeks, and the latter in drier areas. (The under-representation of *Pomaderris* leaves in the creeks seems to be due to fragility as numerous large leaf fragments were recovered, but comparatively few whole leaves.) Leaves of the shrubs *Anopterus glandulosus*, *Cyathodes glauca* and *Coprosma quadrifida* were very rare in the litter collections, and no phylloclades of *Phyllocladus aspleniifolius* were found.

Two species displayed notable variations in abundance between drift and benthic samples. *Atherosperma moschatum* leaves were mainly in drift samples whereas *Phyllocladus aspleniifolius* was more abundant in benthic samples. These differences probably relate to differences in buoyancy and susceptibility to biological and physical breakdown. Sassafras leaves will readily float and are unlikely to reach the benthos intact. This appears to be principally due to leaching and microbiological breakdown and not due to physical destruction since skeletonised leaves were occasionally recovered as well as leaves in which the mesophyll and epidermis were separating. Broken fragments were rarely recovered. Howard (1973) also noted the rapid breakdown of sassafras leaves relative to those of *Nothofagus cunninghamii*.

The longer leaves remain afloat the less chance they will have of settling out undamaged in anaerobic situations where they could become fossilised. The phylloclades of *Phyllocladus aspleniifolius* are comparatively very thick and leathery and it is quite likely that they would both sink rapidly, and therefore not occur in the drift, and be relatively resistant to mechanical or biological breakdown having reached the benthos. It is probable that the benthic phylloclades have been washed from an unknown distance upstream, since trees were not found close to either creek and no phylloclades were found in the transect litter.

Leaves of other species not recorded as proximal shrubs or trees or in the transect litter were of *Aristotelia peduncularis*, *Prionotes cerinthoides*, *Monotoca glauca*, *Leptospermum lanigerum*, *Olearia persoonioides* and *Trochocarpa* sp. In general these small leaves were found in the drift only and seem to have reached the sampling site from unknown distances upstream.

It is considered that the major results found here, i.e. that *Nothofagus cunninghamii* leaves are dominant in both benthic and drift samples, *Atherosperma moschatum* occurs in the drift but only in trace proportions in the benthos samples and *vice versa* for *Phyllocladus aspleniifolius*, and that whole *Eucalyptus obliqua* leaves were absent from all creek samples, are unlikely to be altered significantly by seasonal variation. Turnbull & Madden (1983) found that the number of basal stems at a site accounted for 64% of the variance in litterfall in southern Tasmanian forests. The remaining amount of variation is unlikely to cause a significant shift in the proportions of leaves of the above species in creeks. For instance a drift sample from Tomalah Creek taken in January 1987 comprised a large quantity of *N. cunninghamii* leaves (62% of all whole leaves found), 8% *Atherosperma moschatum* leaves and did not contain *E. obliqua* leaves (with *Eucryphia lucida* forming the bulk of the remaining leaves). These are very similar results to those found during the observation period in October 1986.

It must be stressed that we do not imply that the sample site is a model of a past situation, or that necessarily it represents a potential fossil site or means of litter conveyance to a fossil site. However, we suggest that the evidence presented here may at least in part be used to explain certain features of the fossil record, including the absence of some taxa which are abundant in extant forests. It is of interest that the benthic data obtained in this report reflect the macrofossil composition of Tasmanian Quaternary sites and the Regatta Point Plio-Pleistocene deposit (Colhoun 1980, Hill & Macphail 1985, R.S. Hill, pers. comm. 1987). These deposits tend to be dominated by *Nothofagus*, with *Eucryphia*, *Phyllocladus* and rare *Atherosperma* and *Acacia* macrofossils.

The results suggest that the processes of leaf buoyancy and breakdown and differential litter input mean that the leaves of *Eucalyptus obliqua* and *Atherosperma moschatum* will fossilise only rarely despite trees of these species being locally common, whereas leaves of *Nothofagus cunninghamii* and *Phyllocladus aspleniifolius* will fossilise readily and abundantly, possibly leading to an overestimation of their actual presence in the

surrounding forest. In this respect Hill & Gibson (1986a) predicted, on the basis of the proportions and distribution of leaves in Lake Dobson, that in the surrounding forest *Eucalyptus coccifera* was rare in relation to *Nothofagus cunninghamii*, whereas in fact the eucalypts are the canopy dominants. No reliable eucalypt macrofossils are known from Tasmania. The paucity of fossil leaves assignable to taxa typical of eucalypt dominated sclerophyll vegetation may also be due to the relatively recent spread of this vegetation type associated with the arrival of humans and frequent fires (Singh, Kershaw & Clark 1981). *Eucryphia* is the only true rainforest plant that is well represented in the litter but has virtually no macrofossil record from the Tertiary. There is therefore some evidence that leatherwood is unlikely to have been common in the Tertiary, at least close to water, a habitat in which it is abundant today. Possibly *Eucryphia* spread during and since the late Tertiary cooling and Quaternary glaciations, which seem to have caused the extinction of numerous species from Tasmania (Hill & Macphail 1985). Leaves of the rainforest shrub *Anopterus glandulosus* appear to be very susceptible to rapid physical and biological breakdown. *Aristotelia* leaves seem to be affected similarly to those of *Atherosperma*. It is predicted that they have little potential for fossilisation. In accordance with the results of O'Keefe & Lake (1987) the thick phyllodes of *A. melanoxylon* appear resistant to breakdown, and should thus fossilise readily. Macrofossils of *Acacia* are known only from Plio-Pleistocene and later sediments (Hill & Macphail 1985) and pollen is first recorded in southeastern Australia in the Miocene (Martin 1978). Therefore, if Acacia occurred in the early Tertiary of Tasmania it must have been very remote from depositional sites.

The results of this report emphasise that in a study of a fossil flora the possibility of the existence of different suites of species away from water must be considered, since leaves of these plants are much less likely to reach a situation where they could become fossilised.

ACKNOWLEDGEMENTS

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REFERENCES

BARLOW, B.A., 1981: The Australian flora: its origin and evolution. *In* George, A.S. (Ed.): *FLORA OF AUSTRALIA. VOLUME 1. INTRODUCTION*. Australian Government Publishing Service, Canberra: 25–75.

BIRKS, H.J.B. & BIRKS, H.H., 1980: *QUATERNARY PALAEOBOTANY*. Edwin Arnold, London.

BUNN, S., 1986: Origin and fate of organic matter in Australian upland streams. *In* De Deckker, P. & Williams, W.D. (Eds): *LIMNOLOGY IN AUSTRALIA*. CSIRO, Melbourne. Dr W. Junk Publishers, Dordrecht: 277–292.

COLHOUN, E.A., 1980: Quaternary fluviatile deposits from the Pieman Dam site, western Tasmania. *Proc. R. Soc. Lond. B* 207: 355–384.

FERGUSON, D.K., 1985: The origin of leaf assemblages — new light on an old problem. *Rev. Palaeobot. Palynol.* 46: 117–188.

HILL, R.S., 1983: *Nothofagus* macrofossils from the Tertiary of Tasmania. *Alcheringa* 7: 169–183.

HILL, R.S., 1984: Tertiary *Nothofagus* macrofossils from Cethana, Tasmania. *Alcheringa* 8: 81–86.

HILL, R.S. & GIBSON, N., 1986a: Distribution of potential macrofossils in Lake Dobson, Tasmania. *J. Ecol.* 74: 373–384.

HILL, R.S. & GIBSON, N., 1986b: Macrofossil evidence for the evolution of the alpine and sub-alpine vegetation of Tasmania. *In* Barlow B.A. (Ed.): *FAUNA AND FLORA OF ALPINE AUSTRALASIA*. CSIRO, Canberra: 205–217.

HILL, R.S. & MACPHAIL, M.K., 1983: Reconstruction of the Oligocene vegetation at Pioneer, northeast Tasmania. *Alcheringa* 7: 281–299.

HILL, R.S. & MACPHAIL, M.K., 1985: A fossil flora from rafted Plio-Pleistocene mudstones at Regatta Point, Tasmania. *Aust. J. Bot.* 33: 497–517.

HOWARD, T.M., 1973: Studies in the ecology of *Nothofagus cunninghamii* Oerst. II. Phenology. *Aust. J. Bot.* 21: 79–92.

JARMAN, S.J. & BROWN, M.J., 1983: A definition of cool temperate rainforest in Tasmania. *Search* 14: 81–87.

MARTIN, H.A., 1978: Evolution of the Australian flora and vegetation through the Tertiary: evidence from pollen. *Alcheringa* 2: 181–202

O'KEEFE, M.A. & LAKE, P.S., 1987: The decomposition of pine, eucalypt and *Acacia* litter in a small upland Victorian stream. *Bull. Aust. Soc. Limnol.* 11: 15–32.

RAVEN, P.H. & AXELROD, D.I., 1972: Plate tectonics and Australasian palaeobiogeography. *Science* 176: 1379–1386.

SINGH, G., KERSHAW, A.P. & CLARK, R., 1981: Quaternary vegetation and fire history in Australia. *In* Gill, A.M., Groves, R.H. & Noble, I.R. (Eds): *FIRE AND THE AUSTRALIAN BIOTA*. Australian Academy of Science, Canberra: 23–54.

TURNBULL, C.R.A. & MADDEN, J.L., 1983: Relationship of litterfall to basal area and climatic variables in cool temperate forests of southern Tasmania. *Aust. J. Ecol.* 8: 425–431.

WINTERBOURN, M.J., 1985: Sampling stream invertebrates. *In* Pridmore, R.D. & Cooper, A.B. (Eds): *BIOLOGICAL MONITORING IN FRESHWATERS: PROCEEDINGS OF A SEMINAR*. Water and Soil Miscellaneous Publication 83. Water and Soil Directorate, Ministry of Works and Development for the National Water and Soil Conservation Authority, Wellington, 1985: 241–258.

(accepted 26 November 1987)

A NATURAL REGIONS MAP FOR TASMANIA

by A. E. Orchard

(with two text-figures)

ORCHARD, A. E., 1988 (31:x): A natural regions map for Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 47–51. ISSN 0080–4703. Tasmanian Herbarium, G.P.O. Box 252C, Hobart, Australia 7001.

Tasmania has been divided into 13 regions for the purpose of mapping plant distribution. Eleven of these regions are large ecogeographic zones, the other two being defined to accommodate historic and administrative requirements of the Tasmanian Herbarium. The boundaries of all regions are defined on natural features, principally rivers and altitudinal contours. The region names are being routinely added to labels of specimens in the Tasmanian Herbarium. Very similar regions are recognised in a scheme being used by other agencies in Tasmania for nature conservation purposes, and the differences between the two schemes are discussed.

Key Words: ecogeographic regions, Tasmania, Tasmanian Herbarium.

INTRODUCTION

Botanical regions, based on a range of criteria, have been defined for most Australian states (see Barlow 1984 for a summary). Most schemes have been developed by state herbaria, where they are found to be particularly useful for internal collection management purposes. Many authors also use these schemes as convenient and more or less natural frameworks within which to describe plant distribution, particularly in taxonomic revisions and considerations of plant conservation.

Tasmania has never had a scheme of well-defined botanical regions for a number of reasons. Firstly, the Tasmanian Herbarium was only formally established in 1977/78. Secondly, Tasmania is the smallest state, and in terms of area would fit many times over into some of the botanical regions used in other states. Finally, through a combination of climate, topography, evolutionary history and other factors, Tasmania has perhaps the most intricate mosaic of vegetation types in Australia. As an illustration of this latter point, it is possible, for example, to set up a transect from Pitt Water near Hobart Airport to the top of Mt Wellington, a linear distance of 25 km, which takes in coastal sand-dune communities, salt marshes, dry sclerophyll forest and savannah, riverine wetlands, wet sclerophyll forest, cool temperate rainforest, subalpine heathland and subalpine cushion plant communities. In fact the only major Tasmanian plant communities missing in this transect are the buttongrass swamp and other vegetation types developed on the quartzite/peat soils of the southwest and west coast.

Undefined vernacular descriptors (east coast, midlands, Western Tiers, central plateau, southwest) have been used informally to describe more or less natural regions in Tasmania for many years. Davies (1964) produced a map of the six main contemporary vegetation types in Tasmania (see also Jackson 1965), and Kirkpatrick & Dickinson (1984) provided a much more detailed map which recognised 49 different communities. Mosley (1974) produced a map of 12 "floristic zones", which subsequently formed the basis for some assessments of the distribution and conservation status of individual species and communities, e.g. Brown *et al* . 1977, Leigh *et al.* 1981. The boundaries of these zones were not defined, and some zones encompassed a very wide range of vegetation types. Barlow (1984, 1986) adopted a much simpler approach, by treating the whole of Tasmania as a single botanical region. The Bureau of Flora and Fauna with their *Census of Australian Plants* (unpublished) attempted to relate species distribution in Tasmania to three regions, but again these had undefined boundaries.

In 1980, in the absence of any existing, widely accepted system of botanical regions in Tasmania it was decided to devise one, initially for use only as a management tool within the Tasmanian Herbarium. In drawing up the map, the following criteria were taken into account:

(i) the number of regions was not to exceed 15, and should if possible be fewer;

(ii) the regions were to be biogeographically based, taking into account the climatic regions of Gentilli (1972), the vegetation map of Davies (1964) and the floristic zones of Mosley (1974);

(iii) the boundaries had to be unambiguous, based

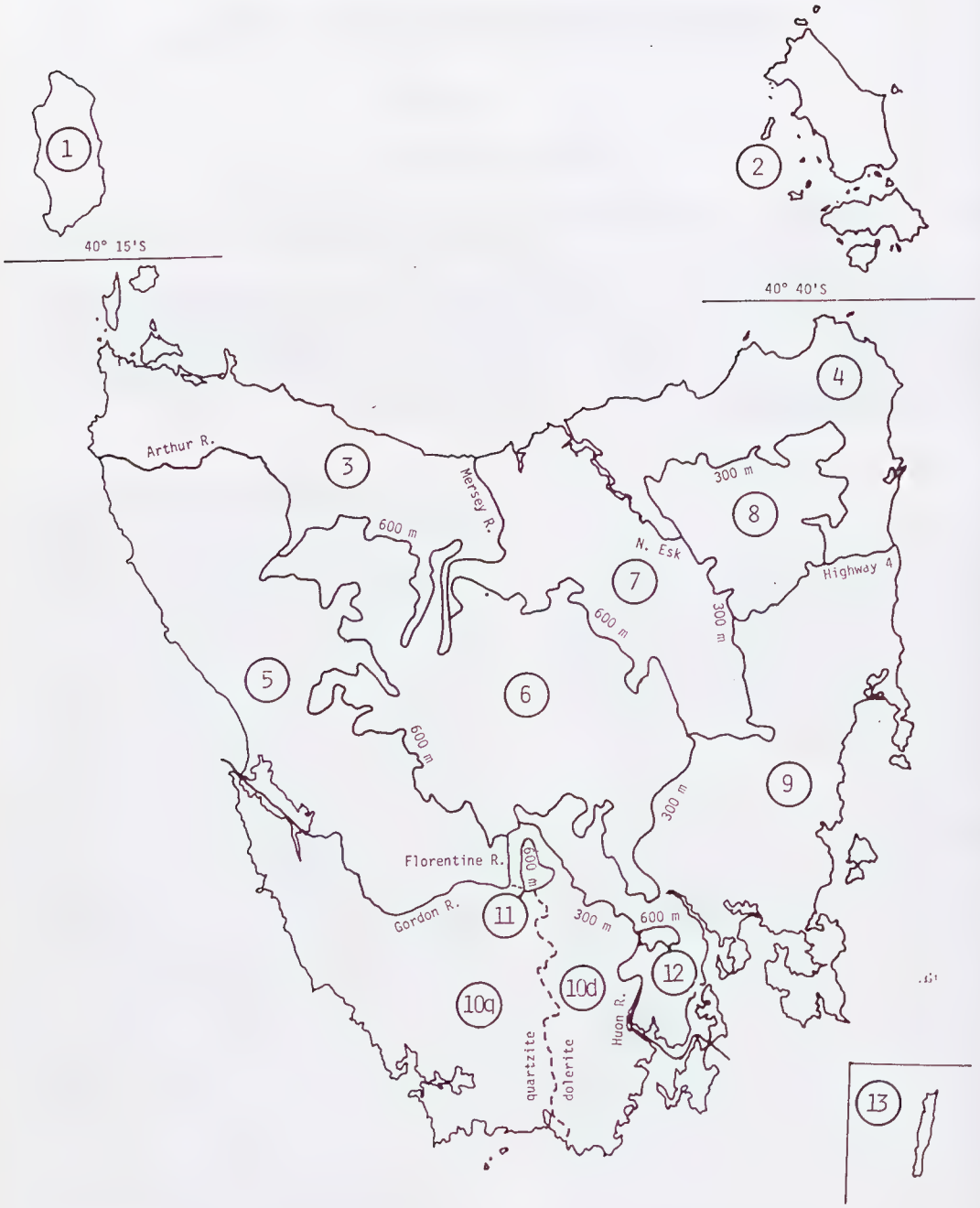

FIG. 1—Regions used by the Tasmanian Herbarium: (1) King Island, (2) Furneaux, (3) North West, (4) North East, (5) West Coast, (6) Central Highlands, (7) Midlands, (8) Ben Lomond, (9) East Coast, (10q) South West (quartzite), (10d) South West (dolerite), (11) Mt Field, (12) Mt Wellington, (13) Macquarie Island.

as far as possible on natural features, and definable in two-three sentences; and
(iv) the names of the regions were to retain, as far as possible, vernacular usage.

THE REGIONS

A set of 13 regions was recognised (fig. 1), and defined.
(1) *King Island.* Includes King Island itself, plus associated islets and reefs north of latitude 40°15'S.
(2) *Furneaux.* Includes the main Furneaux Group (Flinders, Cape Barren and Clarke Islands and associated islets north of latitude 40°40'S) as well as the Kent, Curtis and Hogan Groups up to the Victorian border (latitude 39°12'S).
(3) *North West.* The southwestern boundary is formed by the Arthur River upstream to near Waratah. It then turns eastward along 600 m altitudinal contour. The eastern boundary is the Mersey River. Three Hummock, Hunter and Robbins Islands fall within this region.
(4) *North East.* The western boundary is the Tamar estuary. The southern boundary follows the North Esk River to the 300 m altitudinal contour, then along this line north of the Ben Lomond massif to Highway 4 between Fingal and Scamander.
(5) *West Coast.* Abuts region 3 in the north. The eastern boundary is the 600 m contour line while the southern boundary is Macquarie Harbour and the Gordon River. The southeastern extremity is bounded by the Florentine River.
(6) *Central Highlands.* The northern, western and northeastern boundaries are the 600 m contour line. In the east this contour line is joined to the 300 m line by the Blackman River, and the 300 m line is followed to the Florentine and Gordon Rivers.
(7) *Midlands.* The western boundary is the Mersey River, the eastern boundary is the Tamar Estuary, the North Esk River and then via the 300 m contour along the southeastern and southern boundaries to the Blackman River. On the southwestern side this region abuts the central highlands.
(8) *Ben Lomond.* The Mt Arthur, Mt Barrow, Ben Lomond and Mt Saddleback complex, down to the 300 m contour line.
(9) *East Coast.* In the north the boundary is Highway 4 between Fingal and Scamander, until the point where it meets the 300 m contour. This line forms the western boundary until it meets the Huon River near Judbury. This region includes the upper Derwent Valley and north Bruny Island.
(10) *South West.* Abuts regions 5, 6 and 9 and includes south Bruny Island. Contains region 11 as an enclave. It can be divided into two subregions (q) and (d) defined by the underlying rock type (q = quartzite, d = dolerite).
(11) *Mt Field.* Consists of Mt Field East and Mt Field West, down to the 600 m contour line.
(12) *Mt Wellington.* The Mt Wellington range down to the 600 m contour line.
(13) *Macquarie Island.*

DISCUSSION

Some comments are necessary on the above scheme. Two regions, Mt Field and Mt Wellington, are arbitrary. Both have been singled out for special recognition within the Tasmanian Herbarium because they are the two most heavily collected and botanically visited areas in the state. However, on other criteria Mt Wellington clearly belongs in the South West region, while Mt Field would be allocated to region 6 or 10(d). Some other boundaries are somewhat arbitrary (for example those between regions 3 & 5, and 3 & 7) and have the consequence of stretching vernacular understanding of some districts (e.g. Deloraine and Mole Creek fall within "Midlands", the upper Derwent Valley within "East Coast" and South Bruny Island within "South West"). However these quirks must be tolerated if a manageable number of regions with easily defined boundaries is to be achieved.

These regions have been in use in the Tasmanian Herbarium now for over six years, and have been routinely added to all specimen labels produced in that time. No serious difficulties have been experienced in quickly allocating collections to their correct region. The region names will be used in future editions of *The Student's Flora of Tasmania* and in at least some taxonomic monographs to describe plant distributions within the state.

In 1984 the Tasmanian Forestry Commission convened a meeting to discuss the preparation of definitions of biophysical/biogeographic regions within Tasmania, to be used in the first instance in an Environmental Impact Study on Woodchip Exports (Anon. 1985). The Commission decided to adopt the Herbarium scheme with minor modifications, and produced a map (fig. 2) showing eleven Nature Conservation Regions, each rigidly defined on criteria similar or identical to those of the Herbarium scheme.

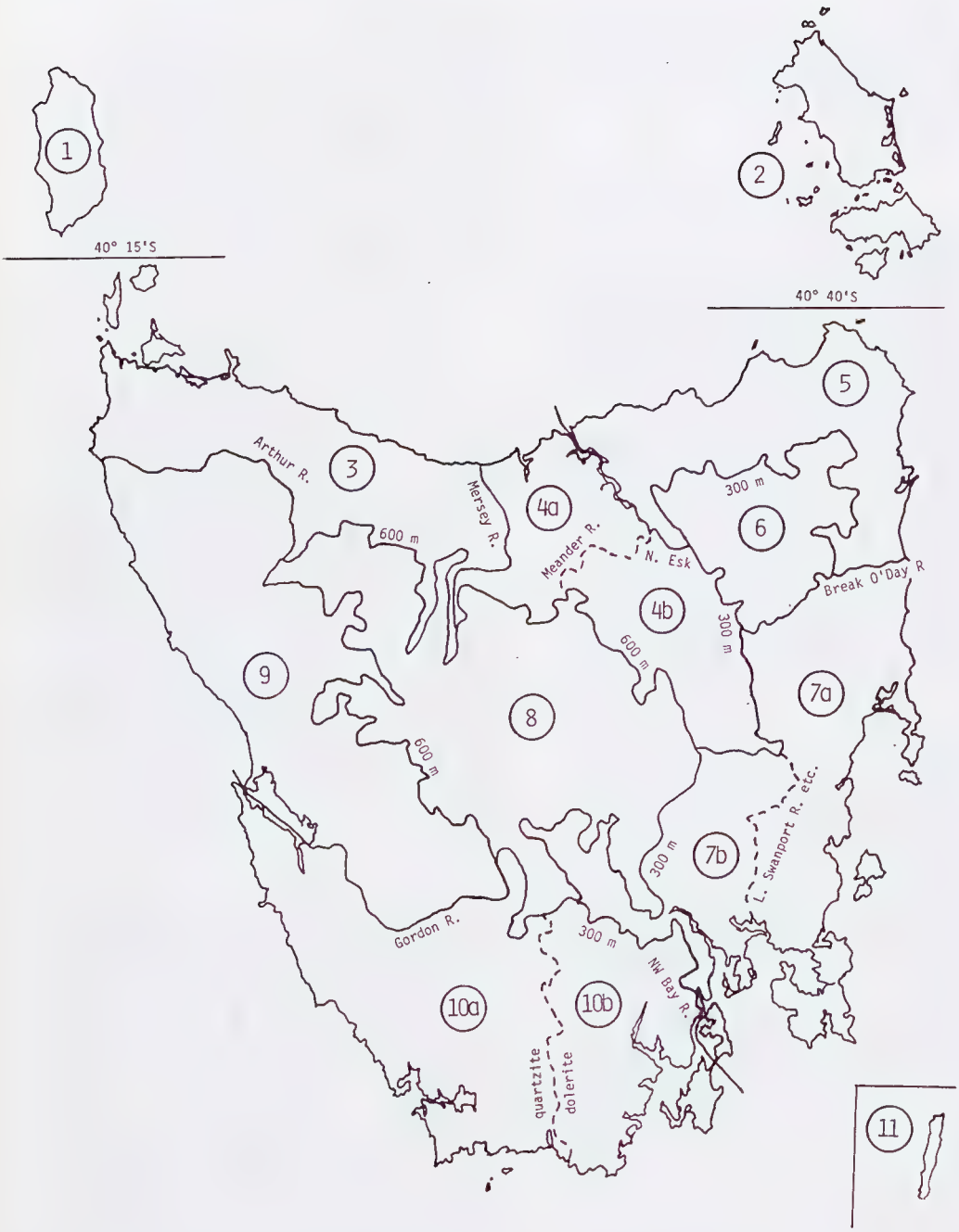

FIG. 2 — Nature Conservation Regions adopted by the Tasmanian Forestry Commission: (1) King Island, (2) Furneaux Group, (3) North west, (4) North (4a –Coast and Hills, 4b – Midlands), (5) North East Lowlands, (6) North East Highlands, (7) East (7a – Coast and Tiers, 7b – Southern Midlands), (8) Centre, (9) West, (10) South (10a – quartzite, 10b – dolerite), (11) Macquarie Island.

The major differences between the two maps (referred to here for convenience as the Herbarium and Forestry schemes) are:
(i) the "Midlands" region of the Herbarium map ("North" on the Forestry map) is divided by Forestry at the Meander River and Quamby Brook into two subregions called "Coast and Hills" and "Midlands";
(ii) the "East Coast" region of the Herbarium map is divided by Forestry along the Tasman Highway, Woodsdale Road, Stonehenge Road, Little Swanport River, Green Tier Creek and Tooms Lake Road into two subregions called "Coast and Tiers" and "Southern Midlands";
(iii) the Herbarium's "Mt Field" region is included within the Forestry "Centre" (= "Central Highlands") region;
(iv) the Herbarium's "Mt Wellington" region is included within the Forestry "South" region; and
(v) in the Forestry scheme the eastern boundary of the "South" (="South West") region is moved eastwards from the Huon River to North West Bay River.

As well as the Forestry Commission, other organisations such as the Tasmanian National Parks and Wildlife Service have adopted the modified scheme for some conservation studies (e.g. Duncan 1986). For most purposes, the two schemes can be considered essentially identical. In critical cases if the source of the particular scheme is being followed is not clearly identified, it should be possible to ascertain this by the nomenclature adopted, which differs for most regions in the Herbarium and Forestry maps.

REFERENCES

ANONYMOUS, 1985: *ENVIRONMENTAL IMPACT STUDY ON TASMANIAN WOODCHIP EXPORTS BEYOND 1988*. Tasmanian Woodchip Study Group, Hobart.

BARLOW, B.A., 1984: Proposal for delineation of botanical regions in Australia. *Brunonia* 7: 195–201.

BARLOW, B.A., 1986: A revised natural regions map for Australia. *Brunonia* 8: 387–92.

BROWN, M.J., HOGGINS, D.D. & BAYLY-STARK, H.J., 1977: Conservation of flora in Tasmania. *Tech. Rep.* 77/4. Tasm. Nat. Pks Wildl. Serv.

DAVIES, J.L., 1964: A vegetation map of Tasmania. *Geog. Rev.* 54: 249–253.

DUNCAN, F., 1986: Vegetation survey of non-allocated Crown land in Tasmania. Report No. 1. *Tech. Rep.* 86/2. Tasm. Nat. Pks Wildl. Serv.

GENTILLI, J., 1972: *AUSTRALIAN CLIMATE PATTERNS*. Nelson, Melbourne.

JACKSON, W.D., 1965: Vegetation. *In* Davies, J. L. (Ed.): *ATLAS OF TASMANIA*. Lands and Survey Department, Hobart.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984: *VEGETATION OF TASMANIA* (Map). Forestry Commission, Tasmania.

LEIGH, J., BRIGGS, J. & HARTLEY, W., 1981: Rare or threatened Australian plants. *Aust. Natl Pks Wildl. Serv. Spec. Pub.* No. 7.

MOSLEY, J.G., 1974: Conservation in Tasmania. *In* Specht, R. L., Roe, E.M. & Boughton, V. H. (Eds.): *CONSERVATION OF MAJOR PLANT COMMUNITIES IN AUSTRALIA AND PAPUA NEW GUINEA*. *Aust. J. Bot. Suppl.* 7: 320.

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A REGIONAL LAPSE RATE FOR TASMANIA

by M. Nunez

(with one table and three text-figures)

NUNEZ, M., 1988: (31:x): A regional lapse rate for Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 53–57. ISSN 0080–4703. University of Tasmania, G.P.O. Box 252C, Hobart, Australia 7001.

A regional lapse rate for Tasmania is derived using stations which record maximum and minimum air temperatures. Sources of errors are identified. Guidelines are described for the efficient application of regional lapse rates to obtain air temperatures in mountainous terrain.

Key Words: lapse rate, Tasmania.

INTRODUCTION

In an earlier paper (Nunez & Colhoun 1986), the gradient of near-surface air temperature with altitude, commonly known as the environmental lapse rate (ELR), was obtained for Mount Wellington, Tasmania. Comparing these local lapse rates with an ELR for the entire island did not give good agreement for maximum temperatures in summer or minimum temperatures in winter. These differences are attributed to microscale factors (sky view, slope, aspect, etc.) and regional factors such as katabatic winds, sea breezes, etc. It was concluded that lapse rates were site specific and it remained to be determined if different mountain ranges would have the same lapse rates even if their base temperatures were to differ.

This information is important in general ecological and palaeoclimatic work (Macphail 1979, Kirkpatrick 1982, Colhoun 1985) in which a gradient in near-surface air temperature with altitude is used in palaeoenvironmental reconstruction. The usual approach is to assume that the ELR remains invariant in time, and that one value of the ELR is applicable for the entire island.

This paper derives a regional lapse rate from air temperature records. Errors associated with estimates of ELR are discussed, along with guidelines for its effective estimation.

METHODOLOGY

A conceptual model of air flow must be developed as a first step in the estimation of a regional ELR. Air temperature at any near-surface location varies with the path of the air flow. An air mass travelling upslope (downslope) will cool (warm) at a rate different from 1°C/100 m since the cooling (warming) may not be adiabatic. The temperature change may be a function of a range of environmental variables which will determine how heat is being exchanged with the surface. Air temperature in a westerly flow, as in the case of Tasmania, is therefore dominated by the characteristics of the upstream westerly path.

Given these considerations, it was decided to define a series of westerly transects across Tasmania (fig. 1) containing two or more stations

FIG. 1—Seven air temperature transects in Tasmania. Black circles represent a station recording maximum and minimum air temperatures.

which record maximum/minimum temperatures. A total of 26 stations and 7 transects were used in the analysis. These stations were selected at distances which varied from a maximum distance of over 80 km to a minimum distance of less than 20 km. The station separation was considered appropriate to treat each pair of adjacent stations as being in the same physical environment as far as regional climate influences are concerned.

Monthly average maximum and minimum air temperatures were obtained for the period 1 April 1978 to 31 March 1979. This time period corresponded to the Mount Wellington study and was specially selected for comparison purposes.

RESULTS

Figure 2A presents a histogram plot of ELR for mean monthly maximum air temperatures. The distribution is normal about a mean value of $-0.0077°C\ m^{-1}$ (median value = $0.0069°C\ m^{-1}$). However the standard deviation at $0.0137°C\ m^{-1}$ is fairly large. Figure 2B shows a similar plot for the ELR of monthly minimum air temperatures. Even more scatter is obtained here, with a mean value of $-0.00515°C\ m^{-1}$ and a standard deviation of $0.024°C\ m^{-1}$. The lapse rate is being influenced by a few station gradients which show very positive results. In contrast the median value of $-0.0028°C\ m^{-1}$ is near the maximum value in the frequency plot.

DISCUSSION

It is evident that the median values in figure 2A and B correspond to a mean regional lapse rate. However the considerable scatter in both figures suggests that there may be other processes, not necessarily random in nature, which significantly influence the lapse rates. If so, then the answer must lie in the processes affecting the cooling or warming of the air parcel in its westerly path.

Figure 3A plots monthly lapse rates of maximum air temperature *versus* terrain slope for the 19 station pairs used in this data set. The pattern shows a high scatter of slopes at absolute magnitude less than 6.0×10^{-3}. At low slope angles processes not related to adiabatic warming and cooling dominate. For example, a westerly air stream, originating in the southern ocean, would gradually warm in its passage across the Tasmanian land mass during a summer day. This continentality effect, not related to cooling of an air mass with altitude, is important at low slope angles. At the other extreme, a steep mountain range would exhibit a marked cooling (or warming) with altitude which would be a result of both adiabatic and non-adiabatic processes. Sea breeze events also present a disruption to the regional ELR pattern. A westerly air stream would gradually warm as it descends from the Central Plateau to the east coast. However cooler coastal temperatures resulting from the sea breeze would indicate a cooling of the air stream rather than a warming as expected from adiabatic warming theory.

The same pattern is exhibited in figure 3B which plots lapse rates of minimum air temperatures *versus* terrain slope. The continentality effect would create a progressive cooling of the westerly air masses as they travel over Tasmania at night. As in figure 3A this effect is most noticeable at low slope angles. Other sources of error at night would include cold air drainage and land breezes. These processes create ponding of cold air at valley bottoms and other low lying areas, therefore disrupting the adiabatic pattern.

From these considerations it seems that some bounds must be placed on the definition of a regional ELR if it is to be used on a practical basis. The results presented here indicate that slopes with an absolute magnitude greater than 6.0×10^{-3} will yield values that are more conservative and representative of the entire island. Table 1 shows ELR data when only slopes greater than 6.0×10^{-3} are accepted in the analysis. Mean lapse rates of $-0.0070°C\ m^{-1}$ and $-0.0037°C\ m^{-1}$ are obtained for the maximum and minimum ELR respectively. Both data sets exhibit a standard deviation of $0.0029°C\ m^{-1}$.

Data from the Mount Wellington study which encompasses six stations is also shown. Values were calculated for four station pairs, each pair separated by a height of over 400 m. Thus a total of 48 data points were available (one station hour per month) which allowed calculation of a mean ELR value and a standard deviation. Close agreement is obtained in the ELR of maximum temperature. Lapse rates for minimum temperatures show more disagreement, although the Mount Wellington value is still within the probable error range of the regional value (see standard deviation). It is interesting to note that both data sets (regional *versus* Mount Wellington) exhibit similar standard deviations. It is likely that microclimatic differences explain a large fraction of the standard deviation in both data sets. This is certainly the case of Mount Wellington where the

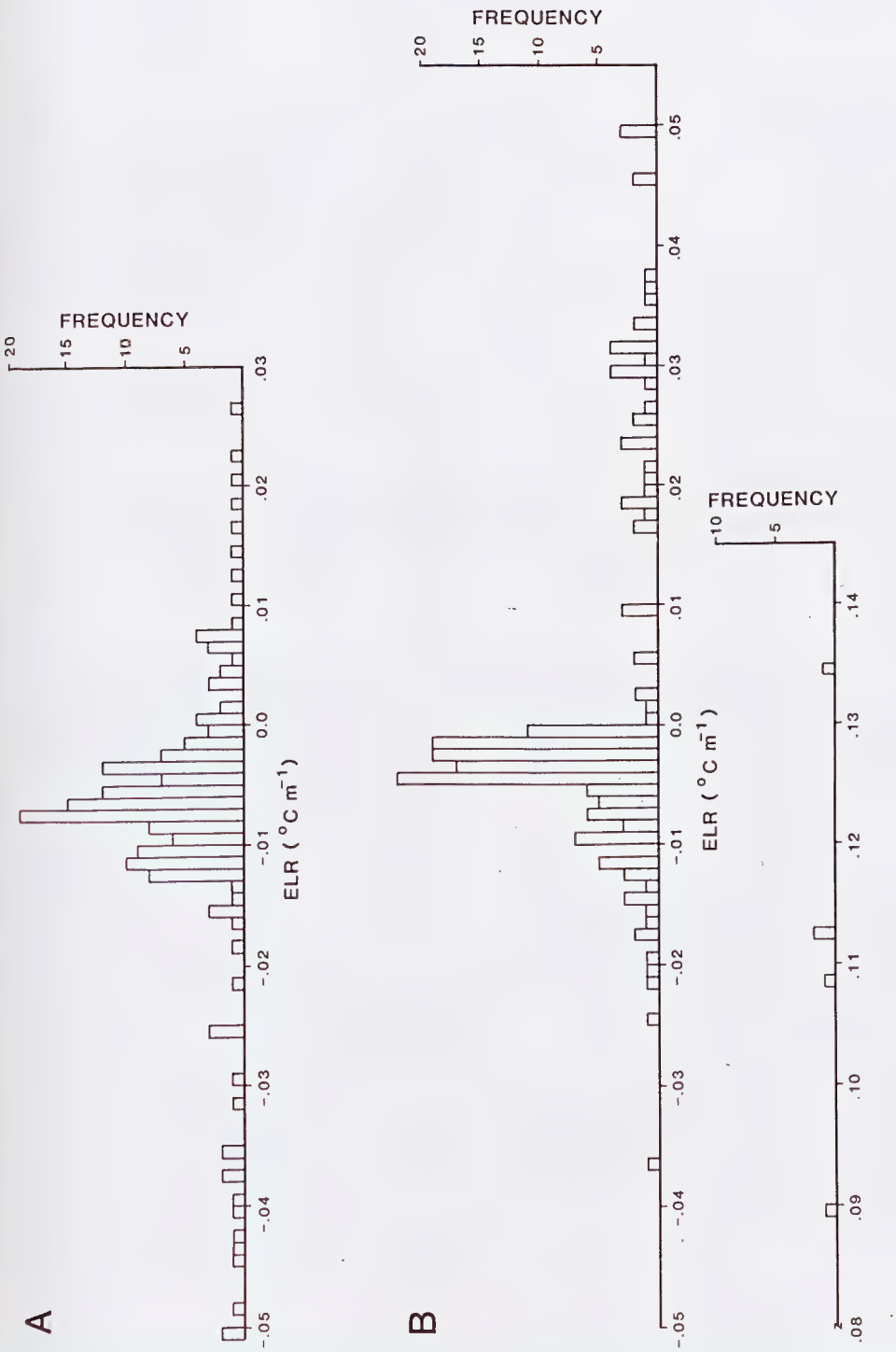

FIG. 2 — Histogram of frequency versus *ELR for 19 adjacent air temperature stations shown in figure 1. (A) ELR refers to monthly maximum air temperatures. (B) ELR refers to monthly minimum air temperatures. Data set covers the period 1 April 1978 to 31 March 1979.*

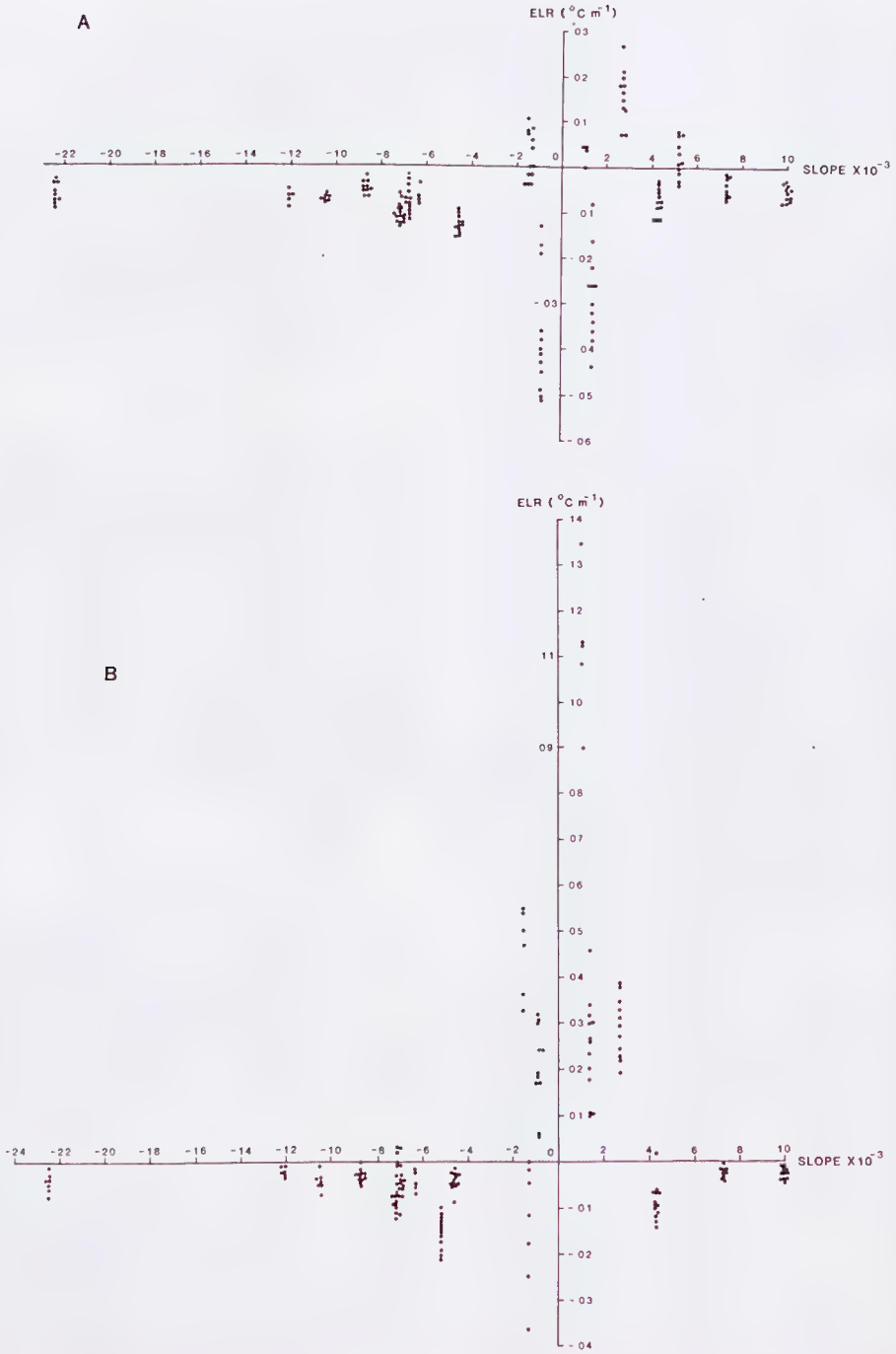

FIG. 3—Plot of terrain slope versus *ELR for 19 adjacent air temperature stations shown in figure 1. (A) ELR refers to monthly maximum air temperatures. (B) ELR refers to monthly minimum air temperatures. Data set covers the period 1 April 1978 to 31 March 1979.*

TABLE 1
ELR Statistics

	This study*	Mt Wellington‡
ELR of maximum temperature (°C m^{-1})	-0.0070	-0.0072
Standard deviation of ELR maximum temperature (°C m^{-1})	0.0029	0.0024
ELR of minimum temperature (°C m^{-1})	-0.0037	-0.0049
Standard deviation of ELR minimum temperature (°C m^{-1})	0.0029	0.0016

* Statistics for 26 adjacent stations in Tasmania with slopes greater than 6.0×10^{-3}; results for the six-station regression are presented.
‡ Data shown here for comparison purposes; statistics for four station pairs separated by a height of over 400 m.

close proximity of all six stations ensures that they are all under the same regional weather system.

The following guidelines, mostly based on this study, are recommended for the effective extrapolation of air temperatures using a regional ELR.
(1) Proper consideration must be given to the dominant air flow and the region to be extrapolated should lie directly downstream of known air temperatures. In Tasmania the dominant air flow is from the west.
(2) The target region where air temperatures are required should subtend a slope of 6.0×10^{-3} or greater with respect to the location where air temperatures are known. Furthermore, the elevation difference between the two points should be over 400 m to ensure that adiabatic cooling or warming are important mechanisms.
(3) The ELR values reported in table 1 are regional figures which have been averaged over a range of microclimates, surface types and terrain slope and aspect. The air temperature estimates for the target areas are therefore regional estimates and errors could occur when applied to a specific location. The magnitude of the error is of course given by the standard deviation in the ELR (0.0029°C m^{-1}). This figure translates as an error of ±0.3°C in the determination of maximum or minimum air temperature in a 100 m height.

REFERENCES

COLHOUN, E.A., 1985: Glaciations of the west coast range, Tasmania. *Quatern. Res.* 24: 39–59.

KIRKPATRICK, J.B., 1982: Phytogeographical analysis of Tasmanian alpine floras. *J. Biogeogr.* 9: 255–271.

KIRKPATRICK, J.B., 1986: Tasmanian alpine biogeography and ecology and interpretations of the past. *In* Barlow, B.A. (Ed.): *FLORA AND FAUNA OF ALPINE AUSTRALASIA: AGES AND ORIGIN*. CSIRO, Melbourne: 228–242.

MACPHAIL, M.K., 1979: Vegetation and climates in southern Tasmania since the last glaciation. *Quatern. Res.* 11: 306–341.

NUNEZ, M. & COLHOUN, E.A., 1986: A note on air temperature lapse rates on Mount Wellington, Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 11–15.

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A RE-EXAMINATION OF JOHN SHIRLEY'S COLLECTION OF TASMANIAN LICHENS

by Gintaras Kantvilas

(with one table and one plate)

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The Tasmanian lichen collection of John Shirley (1849-1922) (housed in the Queensland Herbarium) is examined and re-determined. Two new combinations, *Rinodina asperata* (Shirley) Kantvilas and *Pyrenula galactina* (Shirley) Kantvilas, are proposed, and lectotypes are set up for *Bacidia weymouthii* (Shirley) Zahlbr. and *Pyrenula chloroplaca* Shirley from authentic material. Several lichen records are based on misidentifications and are deleted from the checklist of Tasmanian lichens.

Key Words: Shirley, lichens, Tasmania.

INTRODUCTION

John Francis Shirley was born in Dorchester, England, on 11 August 1849 and died in Brisbane, Australia, on 5 April 1922. He graduated with a Bachelor of Science degree from the University of London where he qualified as a teacher. In 1878, he emigrated to Queensland and was appointed headmaster at Roma in the south of the colony. He became a school inspector in 1879, a position which enabled him to travel widely and which complemented his love of the outdoors and his interests in natural history. He soon became a prominent figure in Australian scientific circles and ultimately became a member of many scientific societies including the Australasian Association for the Advancement of Science (AAAS), the Royal Society of Queensland, the Queensland Field Naturalists, and the Linnaean Society of New South Wales. He published over 40 papers on botany, conchology, zoology and geology. His major work was "The Lichen Flora of Queensland" (Shirley 1888-90) which established him as one of Australia's foremost lichenologists. His dedication to lichenology is perhaps best demonstrated by the fact that whilst on long-service leave he studied this subject for a Doctor of Science degree at Sydney University. He gained his doctorate in 1912 (at the age of 63) and his thesis, entitled "The thallus of the genus *Parmelia*" was subsequently published in Tasmania (Shirley 1918, see also Basset Hull 1923, White 1922).

Shirley's association with Tasmania began in 1892 when he visited Hobart for a meeting of the AAAS, held on 7–16 January. There he studied plants on nearby Mt Wellington and made the acquaintance of William Anderson Weymouth, one of the leading amateur cryptogamic botanists in Tasmania at that time (Kantvilas 1983). In the same year, he became a corresponding member of the Royal Society of Tasmania. His first paper on Tasmanian lichens was a checklist, compiled from earlier literature (Shirley 1893); his second (Shirley 1894), based on his own and Weymouth's collections, represents a major contribution to Tasmanian lichenology. In it he described seven new species and one new variety, and recorded 47 additional species from Tasmania, 13 for the first time.

The bulk of Shirley's collection of Tasmanian lichens is housed in the Queensland Herbarium (BRI) but additional specimens are also known from the National Herbarium of New South Wales (NSW), National Herbarium of Victoria (MEL), and the Conservatoire et Jardin Botanique Genève (G). The lichens are mounted in a large album also containing flowering plants and ferns, which is entitled "Tasmanian Plants Collected on the Slopes and Summit of Mt Wellington, January 1892" (plate 1). Although most of the specimens are from Mt Wellington, a few, especially the lichens, are from other Tasmanian localities, e.g. Tasman Peninsula, Bellerive and Henty River, and represent collections given to Shirley by Weymouth. In fact,

PLATE 1
Selected pages from Shirley's album of Tasmanian lichens, annotated in his own handwriting.

Weymouth is also responsible for more than half of the Mt Wellington lichen collections. The order of the lichen specimens in the album, and their annotations, exactly follow Shirley's paper in 1894, leaving no doubt that this is the collection of specimens upon which the work was based.

The collection is an extremely valuable and important historical resource in Tasmanian lichenology. Firstly, it contains several type specimens of endemic Tasmanian taxa. Several of the new records in the collection are unusual and suspect (e.g. *Sphaerophorus fragilis*) but were maintained in subsequent Tasmanian checklists, e.g. Wetmore (1963) and Filson (1986b). Finally, the collection represents information on the lichen flora of Mt Wellington for the period up to 1892. Massive changes in the area's vegetation have occurred since that time as a result of at least three wildfires (the first in the summer of 1897–98, W. D. Jackson, pers. comm.) and the gradual encroachment of the suburbs of Hobart, at least in the foothills. Accurate historical floristic data, particularly on lichens, will aid in assessing the severity of these changes.

In the present paper, results of a re-examination and re-determination of Shirley's lichen collection are reported.

MATERIALS AND METHODS

Lichens from Shirley's collection were re-examined in the light of recent studies made on the Tasmanian lichen flora (Kantvilas 1985, Kantvilas & James 1987), and present-day accounts from Australasia and the Northern Hemisphere. Identifications were checked where possible against type specimens, type descriptions and/or reliably identified material. Thin-layer chromatography was undertaken using standard methods (Culberson 1972).

RESULTS AND DISCUSSION

The order of species in the following discussion is that adopted by Shirley (1894), and in his mounted collection. Species are listed under Shirley's original nomenclature. Results are summarised in table 1, giving currently accepted names.

(1) *Leptogium chloromelum* var. *granulare* Müll. Arg.

The specimen has an indistinct, small, squamulose thallus and apothecia with sparsely ciliate margins. Spores are simple, 17.5–22 x 9.5–11 µm with a warted epispore. The specimen is clearly *Psoroma hypnorum* (Vahl) S.F. Gray aggr., differing from Northern Hemisphere material of that name (see Jørgensen 1978) chiefly in the smaller spores. As Shirley's is the only record of this species of *Leptogium* from Tasmania, it can now be confidently deleted from the checklist.

(2) *Calicium victoriae* C. Knight ex F. Wilson

Although in very poor condition, the specimen accords with the original description (Wilson 1889). The species is now known as *Mycocalicium victoriae* (C. Knight ex F. Wilson) Tibell (Tibell 1984, 1987).

(3) *Sphaerophoron compressum* Ach.

The specimen contains stictic and constictic acids and sphaerophorin (by tlc) and accords with *Sphaerophorus melanocarpus* (Swartz) DC., in every respect.

(4) *Sphaerophoron coralloides* Pers.

This specimen has flattened main branches, veiled ventral mazaedia and brown spores, 12 µm diameter. It contains sphaerophorin and protocetraric acid (by tlc) and is *Sphaerophoros insignis* Laurer, a common Tasmanian species.

(5) *Sphaerophoron fragile* Pers.

Ohlsson (1974) regards *Sphaerophorus fragilis* as a Northern Hemisphere arctic/alpine species and hence Shirley's record is unusual. The diminutive BRI specimen is in very poor condition, possesses cephalodia and contains atranorin and perlatolic acid. There is no doubt that it is a juvenile *Stereocaulon*, probably *S. ramulosum*, and thus *Sphaerophorus fragilis* should now be deleted from the Tasmanian checklist.

(6) *Sphaerophoron tenerum* Laurer = *Sphaerophorus tener* Laurer

(7) *Baeomyces heteromorphus* Nyl. ex Church. Bab. & Mitten

(8) *Stereocaulon ramulosum* (Swartz) Rauschel

The specimen contains atranorin and perlatolic acid and is typical of the species in Tasmania.

(9) *Stereocaulon proximum* var. *macrocarpioides* (Nyl.) Hue

This taxon was considered synonymous with *S. ramulosum* by Lamb (1977). Shirley's specimen contains atranorin and perlatolic acid and falls within the range of this variable species.

(10) & (11)

These specimens have been excised from Shirley's album some time in the past and could not be checked. They can be referred to *Cladia aggregata* (Swartz) Nyl., and *C. schizopora* (Nyl.) Nyl. respectively, both of which are widespread in Tasmania.

(12)–(22) *Cladonia* spp.

These 11 specimens have also been removed from the album, leaving only the bases of the cut pages. *Cladonia* in Australia is currently under revision (by Dr A. W. Archer, Sydney), and it is likely that many of Shirley's names will ultimately be deleted from the Tasmanian checklist.

(23) *Usnea dasypogoides* Nyl. ex Crombie

The specimen contains usnic and salazinic acids and has sparsely pseudocyphellate and pseudoisidiate branch tips. It is provisionally referred to *Usnea arida* Motyka in the sense of Kantvilas & James (1987) and Galloway (1985), although in general the genus is still very poorly known in Australia.

(24) *Stictina cinnamomea* Rich. [= *Pseudocyphellaria cinnamomea* (A. Rich.) Vainio]

Shirley's specimen has sparse marginal phyllidia, lacks a well-developed midrib on the lower surface, and accords with *Pseudocyphellaria dissimilis* (Nyl.) D. Galloway & P. James. These two species are easily confused (Galloway 1985) and although *P. cinnamomea* (A. Rich.) Vainio was often reported in early Tasmanian literature (as *Stictina cinnamomea*), I have yet to see any Tasmanian material of this species.

TABLE 1
Results of re-examination of Shirley's Tasmanian specimens

Code: 1 — status unchanged; 2 — nomenclatural change; 3 — re-determination.

Code	Shirley's determination (1894)	New determination or name
3	*Leptogium chloromelum* var. *granulare* Müll. Arg.	*Psoroma hypnorum* (Vahl.) S.F. Gray aggr.
2	*Calicium victoriae* Knight	*Mycocalicium victoriae* (Knight) Tibell
3	*Sphaerophoron compressum* Ach.	*Sphaerophorus melanocarpus* (Swartz) DC.
3	*Sphaerophoron coralloides* Pers.	*Sphaerophorus insignis* Laurer
3	*Sphaerophoron fragile* Pers.	*Stereocaulon ramulosum* (Swartz) Räuschel
1	*Sphaerophoron tenerum* Laurer	*Sphaerophorus tener* Laurer
1	*Baeomyces heteromorphus* Nyl.	*Baeomyces heteromorphus* Nyl. ex Church. Bab. & Mitten
1	*Stereocaulon ramulosum* Ach.	*Stereocaulon ramulosum* (Swartz) Räuschel
2	*Stereocaulon proximum* var. *macrocarpioides* Nyl.	*Stereocaulon ramulosum* (Swartz) Räuschel
3	*Usnea dasypogoides* Nyl.	?*Usnea arida* Motyka
3	*Stictina cinnamomea* Rich.	*Pseudocyphellaria dissimilis* (Nyl.) D. Galloway & James
P.		
3	*Sticta freycinetii* Delise	*Pseudocyphellaria glabra* (J.D. Hook. & Taylor) Dodge
3	*Sticta dissimulata* Nyl.	*Pseudocyphellaria multifida* (Nyl.) D. Galloway & P. James
2	*Sticta fossulata* Duf.	*Pseudocyphellaria faveolata* (Delise) Malme
3	*Sticta fossulata* var. *physciospora* Nyl.	*Pseudocyphellaria billardierei* (Delise) Räsänen
1	*Parmelia tenuirima* Tayl.	*Parmelia tenuirima* J.D. Hook. & Taylor
3	*Parmelia olivacea* Ach.	*Menegazzia testacea* P. James & D. Galloway
3	*Parmelia pertusa* Schrank	*Menegazzia weindorferi* (Zahlbr.) R. Sant.
3	*Parmelia physodes* Ach.	*Hypogymnia mundata* (Nyl.) Rassad.
3	*Parmelia physodes* var. *placorhodioides* Nyl.	*Hypogymnia turgidula* (Bitter) Elix
3	*Theloschistes parietinus* Norm.	*Xanthoria ligulata* (Körber) P. James
3	*Psoroma sphinctrinum* Nyl.	*Psoroma microphyllizans* (Nyl.) D. Galloway
3	*Psoroma sphinctrinum* var. *pholidotoides* Nyl.	*Psoroma microphyllizans* (Nyl.) D. Galloway
3	*Placodium gelidum* Körber	*Placopsis brevilobata* (Zahlbr.) Lamb
1	*Callopisma cinnabarina* Müll. Arg.	*Caloplaca cinnabarina* (Ach.) Zahlbr.
1	*Biatora immarginata* R.Br.	*Lecidea immarginata* R.Br.
3	*Biatora russula* Ach.	*Lecidea laeta* Stirton
2	*Biatora cera-rufa* Shirley	*Lecidea cera-rufa* (Shirley) Zahlbr.
3	*Patellaria melanotropa* Nyl.	*Catillaria tasmanica* Räsänen
2	*Patellaria weymouthii* Shirley	*Bacidia weymouthia* (Shirley) Zahlbr.
3	*Buellia disciformis* Fr.	*Catinaria grossa* (Pers. ex Nyl.) Vainio
2	*Buellia parasema* Th.Fr.	*Buellia disciformis* (Fr.) Mudd.
2	*Buellia polospora* var. *asperata* Shirley	*Rinodina asperata* (Shirley) Kantvilas
3	*Blastenia consanguinea* Müll. Arg.	*Megaloblastenia marginiflexa* (J.D. Hook. & Taylor) Sipman
2	*Heterothecium pauciseptatum* Shirley	*Austroblastenia pauciseptata* (Shirley) Sipman
3	*Coenogonium acrocephalum* Müll. Arg.	*Coenogonium implexum* Nyl.
3	*Arthonia multiformis* Shirley	*Arthothelium ilicinum* (Taylor) P. James
3	*Chiodecton perplexum* Nyl.	*Chiodecton colensoi* (Massal.) Müll. Arg.
2	*Pseudopyrenula galactina* Shirley	*Pyrenula galactina* (Shirley) Kantvilas
1	*Pyrenula chloroplaca* Shirley	

(25) *Sticta freycinetii* Delise

This specimen is *Pseudocyphellaria glabra* (J.D. Hook. & Taylor) Dodge [= *P. delisea* (Fée) D. Galloway & P. James], a common austral species related to *P. freycinetii* (Delise) Malme. The two taxa have been frequently confused but *Pseudocyphellaria freycinetii* is a South American taxon while *P. glabra* is known from Australasia, cool temperate South America and the subantarctic islands (Galloway & James 1986).

(26) *Sticta dissimulata* Nyl.

This specimen is referable to *Pseudocyphellaria multifida* (Nyl.) D. Galloway & P. James [= *P. subvariabilis* (Nyl.) Vainio], a common Tasmanian wet forest lichen.

(27) *Sticta fossulata* Dufour

This taxon is a synonym of *Pseudocyphellaria billardierei* (Delise) Räsänen (Galloway 1988). Shirley's specimen contains physciosporin (Code B of Wilkins & James 1979) and represents typical material of *P. faveolata* (Delise) Malme.

(28) *Sticta fossulata* var. *physciospora* Nyl.

This name is a synonym of *Pseudocyphellaria physciospora* (Nyl.) Malme, a species known only from the subantarctic islands of New Zealand, and Juan Fernandez (see Galloway 1988). Shirley's specimen has Code C chemistry (see Wilkins & James 1979, methyl evernate, tenuiorin etc.) and is *P. billardierei* (Delise) Räsänen.

(29) *Parmelia tenuirima* J.D. Hooker & Taylor

The specimen is typical of this common Australasian species and contains atranorin and salazinic acid.

(30) *Parmelia olivacea* Ach.

Parmelia olivacea is confined to the Northern Hemisphere (Esslinger 1977). Most records of the species in Tasmania are from rocks or soil (e.g. Wilson 1893) and probably refer to *Parmelia pulla* Ach. [= *Neofuscelia pulla* (Ach.) Esslinger], the most common brown *Parmelia* s.lat. in Tasmania. Shirley's specimen is on a twig and is *Menegazzia testacea* P. James & D. Galloway. It has characteristic 2-spored asci and contains atranorin, stictic acid and menegazziaic acid (by tlc).

(31) *Parmelia pertusa* Schrank

This name, a synonym of the Northern Hemisphere species *Menegazzia terebrata* (Hoffm.) Massal., was widely misapplied in the literature to many Tasmanian species of *Menegazzia*. Shirley's specimen is of *M. weindorferi* (Zahlbr.) R. Sant., and contains protolichesterinic and lichesterinic acids and atranorin.

(32) *Parmelia physodes* Ach.

The name *Parmelia physodes* has been generally misapplied in the past to several Tasmanian species of *Hypogymnia*. Shirley's specimen has discrete, elongated, solid lobes, lacks soredia and has a Pd- medulla, all features of *H. mundata* (Nyl.) Rassad.

(33) *Parmelia physodes* var. *placorhodioides* Nyl.

Elix (1979) considered this name to be a synonym of *Hypogymnia billardierei* (Mont.) Filson. However, Shirley's specimen has hollow lobes, contiguous at the centre of the thallus but discrete at the margins, a Pd- medulla, and is *H. turgidula* (Bitter) Elix, the most common species of *Hypogymnia* in Tasmania's wet forests.

(34) *Theloschistes parietinus* Norm. [= *Xanthoria parietina* (L.) Th.Fr.]

This specimen is referred to the common saxicolous coastal species *Xanthoria ligulata* (Körber) P. James (previously called *X. ectanea* (Ach.) Räsänen by Filson 1969). It has narrow convex lobes with down-turned apices and sparsely lobulate margins and is thus distinct from *X. parietina*.

(35) & (36) *Psoroma sphinctrinum* Nyl. and *Psoroma sphinctrinum* var. *pholidotoides* Nyl.

Specimens of numbers 35 and 36 both have laciniate, radiating lobes with lobulate margins and small, contiguous, globose or flattened phyllidia and thus accord well with *P. microphyllizans* (Nyl.) D. Galloway, in the sense of Kantvilas & James (1987).

(37) *Placodium gelidum* Körber [=*Placopsis gelida* (L.) Lindsay]

The genus *Placopsis* is poorly known in Tasmania and, as no spores could be found in Shirley's scanty specimen, identification was impossible. The specimen is cream-coloured,

esorediate, with well-developed, convex, marginal lobes, brownish-cream, pruinose apothecia and a C^+ red medulla. It is probably better referred to *P. brevilobata* (Zahlbr.) Lamb (*sensu* Galloway 1985).

(38) *Callopisma cinnabarina* Müll. Arg. [=*Caloplaca cinnabarina* (Ach.) Zahlbr.]

The genus *Caloplaca* is poorly known in Tasmania. Shirley's specimen is of a saxicolous coastal species lacking marginal lobes and with spores 11.5–14.5 x 7–8.5 µm, with septa 2.5–5.0 µm thick.

(39) *Biatora immarginata* R.Br. [=*Lecidea immarginata* R.Br.]

First described from New South Wales, *Lecidea immarginata* is widespread in wet forest in Tasmania and will be discussed in detail in a forthcoming paper on rainforest species.

(40) *Biatora russula* Ach. [= *Lecidea russula* Ach.]

Although no mature spores were seen, all other features indicate that Shirley's specimen is the widespread and common Australasian species, *Lecidea laeta* Stirton. The name *Lecidea russula* should be deleted from the Tasmanian checklist.

(41) *Biatora cera-rufa* Shirley [=*Lecidea cera-rufa* (Shirley) Zahlbr.]

This distinctive species is known to me only from Shirley's type collection. In addition to Shirley's notes, it has the following anatomical characteristics: epithecium red-brown, unchanged in KOH; hymenium colourless, I^+ deep blue, 80–100 µm thick; hypothecium colourless to pale yellow-brown, 60–120 µm thick, unchanged in KOH; paraphyses simple, separating easily in KOH; spores simple, broadly ellipsoid, 16.5–19.5 x 9.5–12 µm (somewhat larger than in Shirley's description). Thallus chemistry includes a UV^+ unknown substance.

Holotype: Tasmania. On bark, Bower Track, Mt Wellington, *W.A. Weymouth* No.141 (Filson 1986a: 26). BRI 351374!

(42) *Patellaria melanotropa* Nyl. [= *Catillaria melanotropa* (Nyl.) Zahlbr.]

Shirley's specimen is in extremely poor condition and no mature spores were found. However, in gross morphology, habitat ecology and thallus chemistry (atranorin) it accords well with *Catillaria tasmanica* Räsänen, a common Tasmanian species which still abounds in Shirley's collecting locality (Mt Wellington).

(43) & (44) *Patellaria taitensis* Mnt. [=*Megalospora sulphurata* Meyen] and *Patellaria biclipea* Shirley [= *Megalospora biclipea* (Shirley Zahlbr.]

Specimens 43 and 44 are both missing from the album and there is no sign (e.g. cut pages, blank spaces) that they were ever present. The missing specimens were sought without success in the herbaria of Melbourne, Sydney and Brisbane, all of which house some of Shirley's material. According to Sipman (1983), *Megalospora sulphurata* does not occur in Tasmania, although Shirley's name may have been misapplied to another species of *Megalospora*. However, a recent search of his collecting area did not locate any species of this genus. The loss of the second specimen is more acute as it represents the holotype, as well as the only specimen of *Megalospora biclipea*. However, Shirley's description, and his observation that it is related to *Catinaria grossa* (Pers. ex Nyl.) Vainio, suggests that the species is most likely a *Catinaria* s.lat. (see also Sipman 1983), possibly even a shade form of *Catillaria tasmanica* Räsänen, a species occurring very commonly in the area today. A copy of Shirley's manuscript, in William Weymouth's hand, was found amongst some of Weymouth's papers (donated by Mrs M. Bennet, Cradoc, Tasmania). In this copy, the text concerning the two missing specimens is also missing, except for an inserted note referring to some additional pages. Thus it appears that these two lichens were never part of the original collection but were included later. How or why Weymouth possessed a hand-written version of the paper is unclear. Perhaps his contribution to the text was greater than indicated; after all, the specimens were almost exclusively his, whilst Shirley's main contribution was in their identification. As Shirley was only a corresponding member of the Royal Society of Tasmania, it is possible that Weymouth may have revised and submitted the paper on his behalf, although no record of the latter was found in the Society's minutes or proceedings.

(45) *Patellaria weymouthii* Shirley [= *Bacidia weymouthii* (Shirley) Zahlbr.]

Bacidia weymouthii is a common wet forest species of smooth bark and is discussed in detail in Kantvilas (1985).

Lectotype (selected here): Tasmania. On bark, St Crispins, Mt Wellington, *W. A. Weymouth*, BRI 351374!

Isotype: On bark of tree, St Crispins, Mt Wellington, Tasmania. *W.A. Weymouth* 112, 10/3/91, MEL 7048! (Filson 1986a: 219).

A third collection of this species (cited in Shirley 1894) was not located.

(46) *Buellia disciformis* (Fr.) Mudd.

Examination of Shirley's specimen revealed 1-septate, hyaline spores, indicating that it is not a *Buellia*. Rather, it appears to be a species of *Catillaria* s.lat., with the following apothecial characters: epithecium brown-black, unchanged in KOH; hymenium colourless, 120–190 µm thick; hypothecium greenish-black, opaque, unchanged in KOH; outer edge of excipulum similarly coloured but colourless within; spores hyaline, 1-septate, 26.5–34 x 12–16 µm with a distinct wall, c. 1 µm thick. The specimen closely resembles *Catinaria grossa* (Pers. ex Nyl.) Vainio (see Poelt & Vezda 1981) although the apothecia are rather small and mostly <1 mm diameter. A second specimen of the species is included under "*Heterothecium pauciseptatum*" (see no.50) below.

(47) *Buellia parasema* Th.Fr. [*B. parasema* (Ach.) De Not.]

Santesson (1984) placed *Buellia parasema* as a synonym of *B. disciformis* (Fr.) Mudd., and Shirley's specimen appears to accord with the description of that species given in Poelt (1969). Its spores are 16.5–24 x 7–10 µm, dark brown, thin-walled; epithecium dark brown; hymenium colourless to pale brown, 70–95 µm thick, interspersed with oil droplets; hypothecium dark brown. The genus *Buellia* is still poorly known in Tasmania and requires detailed study and revision.

(48) *Buellia polospora* var. *asperata* Shirley

Sheard (1967) placed *Buellia polospora* (Leighton) Shirley as a synonym with *Rinodina biloculata* (Nyl.) Sheard. However, Shirley's specimen differs from authentic *R. biloculata* in the larger, polarilocular (not placodiomorph) spores, colourless, thicker hypothecium, and the presence of a persistent thalline margin. Corticolous species of *Rinodina* are poorly known in Tasmania. However, until a revision is undertaken, in my opinion Shirley's taxon warrants specific rank:

Rinodina asperata (Shirley) Kantvilas comb. nov.

Basionym: *Buellia polospora* var. *asperata* Shirley, *Pap. Proc. R. Soc. Tasm.* (1893): 218, 1894.

Thallus thin, rather scurfy, pale grey, prothallus absent. Apothecia lecanorine, sessile, dispersed, to 0.4 mm diam. Disc plane to slightly convex, brownish black. Thalline margin thin, entire, somewhat discoloured in older apothecia. Hymenium 70–85 µm thick, colourless. Epithecium red-brown. Hypothecium colourless, to 120 µm thick at centre of apothecia. Paraphyses c. 1 µm thick, apices markedly capitate, 2–3 µm thick. Spores brown, 8 per ascus, polarilocular, very thick walled, lumina rounded when mature, 16.5–22 x 8.5-13 µm.

Holotype: Tasmania. On bark, Fork Creek, *W.A. Weymouth* No.144, BRI!

Isotype: G (see Filson 1986a: 33).

The species is known only from the type collection from the southern slopes of Mt Wellington.

(49) *Blastenia consanguinea* Müll. Arg.

Shirley's specimen is *Megaloblastenia marginiflexa* (J.D. Hook. & Taylor) Sipman. As this was the only Australian record of *Blastenia consanguinea*, this name can now be deleted from the Australian checklist (Filson 1986b).

(50) *Heterothecium pauciseptatum* Shirley [=*Austroblastenia pauciseptata* (Shirley) Sipman]

When Sipman (1983) selected a specimen in NSW as the type (see also Filson 1986a: 96), he was unaware of the existence of Shirley's album collection. Given that Shirley's paper was based on this collection, the album specimen should be considered as holotype, whereas the NSW specimen (NSW L4385) is correctly an isotype. The specimen of *Austroblastenia* is mounted in the album beside a specimen of *Catinaria grossa* s.lat.

(51) *Coenogonium acrocephalum* Müll. Arg.

Shirley's specimen, representing the only record of this taxon from Tasmania, is identical with reliably identified (by Dr A. Vezda, Brno) material of *C. implexum* Nyl., the common and widespread species of *Coenogonium* in Tasmania. Other species of the genus recorded from Tasmania in earlier literature are *C. linkii* Ehrenb. ex Nees and *C. rigidulum* Müll. Arg. It is likely that these records also refer to *C. implexum*.

(52) *Arthonia multiformis* Shirley

Shirley's specimen is the type of this species and is identical with reliably identified material (by Dr A. Vezda, Brno, and Mr P.W. James, London) of *Arthothelium ilicinum* (Taylor) P. James (see Kantvilas 1985). The species has characteristic spores with an enlarged terminal locule and lacks longitudinal septa.

Holotype: Tasmania. On bark, near Hobart, *W.A. Weymouth* No. 111, BRI 351373! (see also Filson 1986a: 16).

(53) *Chiodecton perplexum* Nyl.

This specimen is in poor condition but appears to be identical with *Chiodecton colensoi* (Massal.) Müll.) Arg., a common wet forest species in Tasmania, also known (and first described) from New Zealand.

(54) *Pseudopyrenula galactina* Shirley

This specimen has brown, mature spores and slender, simple paraphyses, suggesting it is a species of *Pyrenula*. On the basis of Shirley's specimen, and recent collections, the species is redescribed below.

Pyrenula galactina (Shirley) Kantvilas comb.nov.

Basionym: *Pseudopyrenula galactina* Shirley, *Pap. Proc. R. Soc. Tasm.* (1893): 219, 1894.

Thallus crustose, thin to rather thick, deeply cracked, greyish white, pale yellowish or olive-grey, forming spreading patches to 10 cm across, not delimited at margins. Perithecia numerous, immersed, obscured by cortex, occasionally sub-emergent, becoming eroded, excavate and forming blackish pits to c. 0.3 mm diam. Ostiole central, minute, punctate, blackish, often with a grey rim. Paraphyses slender, simple to sparingly branched, free. Spores soon becoming brownish, ellipsoid, 14–22(–26) x 5–10 µm, 4-locular, not constricted at septa, arranged in the ascus obliquely in a single row. Locules lenticellular, rhomboid or hexagonal, ± equal sized.

Chemistry: Thallus K+ orange-brown, KC-, Pd- C, UV+ orange (sometimes faintly); lichexanthone (by tlc).

Holotype: Tasmania. On bark, St Crispins, *W. A. Weymouth*, No.113, BRI 351370! (Filson 1986a: 248).

Additional specimens examined: Tasmania. Mt Victoria Road, on *Phyllocladus aspleniifolius* in rainforest, 780 m, 9.xii.1981, *G. Kantvilas* 1097/81, herb. Kantvilas, BM. Ben Ridge Road, on *Nothofagus cunninghamii* in rainforest, 850 m, 10.xii.1981, *G. Kantvilas* 1188/81, herb. Kantvilas.

(55) *Pyrenula chloroplaca* Shirley

This distinctive species is still known only from Shirley's type specimen. It has a yellowish-cream thallus, UV+ bright orange (suggesting lichexanthone) and brown, 4-locular spores, 14–22 x 8–12 µm, the pical locules very small. Two collections (both by Weymouth) are specified in Shirley's paper but the whereabouts of the second is unknown.

Lectotype (selected here): Tasmania. On bark, St Crispins, *W.A. Weymouth* No.114, BRI 351369! (Filson 1986a: 252).

The pyrenocarpous lichens as a group remain poorly understood in Tasmania and require considerable further collection and study.

ACKNOWLEDGEMENTS

I thank Dr D. J. Galloway, Mr P. W. James, Dr S. J. Jarman and Dr A. E. Orchard for helpful comments on various aspects of the work, and the curators and staff of the Queensland Herbarium and Tasmanian Herbarium for arranging loans of specimens. I also thank Mrs M. Bennet for providing original extracts from Mr W. A. Weymouth's papers. The receipt of a National Research Fellowship is gratefully acknowledged.

REFERENCES

BASSETT HULL, A.F., 1923: Presidential address. Proc. Linn. Soc. N.S.W. 48: vii–viii.

CULBERSON, C.F., 1972: Improved conditions and new data for the identification of lichen products by a standardised thin-layer chromatographic method. J. Chromatogr. 72: 113–125.

ELIX, J.A., 1979: A taxonomic revision of the lichen genus Hypogymnia in Australasia. Brunonia 2: 175–245.

ESSLINGER, T.L., 1977: A chemosystematic revision of the brown Parmeliae. J. Hattori bot. Lab. 42: 1–211.

FILSON, R.B., 1969: A review of the genera Teloschistes and Xanthoria in the lichen family Teloschistaceae in Australia. Muelleria 2: 65–115.

FILSON, R.B., 1986a: INDEX TO TYPE SPECIMENS OF AUSTRALIAN LICHENS: 1800–1984. Bureau of Flora and Fauna, Canberra.

FILSON, R.B., 1986b: CHECKLIST OF AUSTRALIAN LICHENS. Second edition, National Herbarium of Victoria, Melbourne.

GALLOWAY, D.J., 1985: FLORA OF NEW ZEALAND LICHENS. Government Printer, Wellington.

GALLOWAY, D.J., 1988: Studies in Pseudocyphellaria (lichens). I. The New Zealand species. Bull. Br. Mus. nat. Hist. (Bot.) 17: 1–267.

GALLOWAY, D.J. & JAMES, P.W., 1986: Species of Pseudocyphellaria Vainio (Lichenes) recorded in Delise's "Histoire des Lichens: Genre Sticta". Nova Hedwigia 42: 423–490.

JØRGENSEN, P.M., 1978: The lichen family Pannariaceae in Europe. Opera Botanica 45: 1–124.

KANTVILAS, G., 1983: A brief history of lichenology in Tasmania. Pap. Proc. R. Soc. Tasm. 117: 41–51.

KANTVILAS, G., 1985: Studies on Tasmanian rainforest lichens. Unpubl. Ph.D. thesis, Univ. Tasm.

KANTVILAS, G. & JAMES, P.W., 1987: The macrolichens of Tasmanian rainforest: key and notes. Lichenologist 19: 1–28.

LAMB, I.M., 1977: A conspectus of the lichen genus Stereocaulon (Schreb.) Hoffm. J. Hattori bot. Lab. 43: 191–335.

OHLSSON, K., 1974: A revision of the lichen genus Sphaerophorus. Unpubl. Ph.D. thesis, Michigan State Univ.

POELT, J., 1969: BESTIMMUNGSSCHLÜSSEL EUROPÄISCHER FLECHTEN. J. Cramer, Vaduz.

POELT, J. & VEZDA, A., 1981: BESTIMMUNGS-SCHLÜSSEL EUROPÄISCHER FLECHTEN. ERGANZUNGSCHEFT II. J. Cramer, Vaduz.

SANTESSON, R., 1984: THE LICHENS OF SWEDEN AND NORWAY. Swedish Museum of Natural History, Uppsala and Stockholm.

SHEARD, J.W., 1967: A revision of the lichen genus Rinodina (Ach.) Gray in the British Isles. Lichenologist 3: 328–367.

SHIRLEY, J., 1888–90: The lichen flora of Queensland I–IV. Proc. R. Soc. Qld 5: 80–110; 6: 5–55, 129–145, 165–218.

SHIRLEY, J., 1893: A list of the known lichens of Tasmania. Pap. Proc. R. Soc. Tasm. (1892): 179–191.

SHIRLEY, J., 1894: Notes on Tasmanian lichens. Pap. Proc. R. Soc. Tasm. (1893): 214–219.

SHIRLEY, J., 1918: The thallus of the genus Parmelia. Pap. Proc. R. Soc. Tasm. (1918): 53–68.

SIPMAN, H.J.M., 1983: A monograph of the lichen family Megalosporaceae. Biblioth. Lich. 18: 1–241.

TIBELL, L., 1984: A reappraisal of the taxonomy of Caliciales. Beih. Nova Hedwigia 79: 597–713.

TIBELL, L., 1987: Australasian Caliciales. Symb. Bot. Upsal. 27: 1–279.

WETMORE, C.M., 1963: Catalogue of the lichens of Tasmania. Rev. Bryol. et Lichenol. 32: 223–264.

WHITE, C.T., 1922: Presidential address. Proc. R. Soc. Qld 34: 2–3.

WILKINS, A.L. & JAMES, P.W., 1979: The chemistry of Pseudocyphellaria impressa s.lat. in New Zealand. Lichenologist 11(3): 271–281.

WILSON, F.R.M., 1889: A description of forty-one Victorian lichens new to science. Vict. Nat. 6: 61–69.

WILSON, F.R.M., 1893: Tasmanian lichens. Pap. Proc. R. Soc. Tasm. (1892): 133–178.

(accepted 6 February 1988)

AN ASSESSMENT OF THE CAROLINE CREEK FRESHWATER CRAYFISH RESERVE IN NORTHERN TASMANIA

by P. Horwitz and P. Hamr

(with one text-figure)

HORWITZ, P. & HAMR, P., 1988 (31:x): An assessment of the Caroline Creek crayfish reserve in northern Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 69–72. ISSN 0080–4703. Centre for Environmental Studies and Department of Zoology, University of Tasmania, G.P.O. Box 252C, Hobart, Australia 7001.

A preliminary investigation of the Caroline Creek freshwater crayfish reserve was conducted over a three-day period in 1987. Data are presented to show that the population numbers of *Astacopsis gouldi*, for which the reserve was gazetted, are low and that large and mature animals were not found. The presence of numerous bait lines throughout the reserve shows that illegal fishing has occurred and is continuing, and suggests that management practices for the reserve have been inappropriate. The need for effective reserves for *A. gouldi* is discussed.
Key Words: freshwater crayfish, fishing reserve, northern Tasmania.

INTRODUCTION

The freshwater crayfish or lobster *Astacopsis gouldi* Clark is endemic to Tasmania, occurring in most river systems draining north into Bass Strait, and in Arthur River in northwestern Tasmania (Swain *et al.* 1982). Early records of the species given by Gould (1870) and Smith (1909) indicate that during the early part of European occupation, the species was plentiful in Tasmania. In particular, specimens of this species were noted to be extremely large, approaching 4-5 kg in weight and might therefore have been regarded as the largest freshwater crayfish in the world (see for instance Francois 1960). The large size of the crayfish makes fishing for the species a popular recreational pastime for inhabitants of northern Tasmania.

In partial response to this popularity, and in order "... to (study) the habitats of the crayfish ..." (Lynch 1969), the Tasmanian Government declared a fishing reserve at Caroline Creek near Latrobe in northern Tasmania (*Inland Fisheries Regulations* 1973), in which fishing is illegal.

In recent times, increased accessibility of remote populations has led to the realisation that fishing pressure on *A. gouldi* might be deleterious to the species. Indeed, this contributed to listing of the species as "vulnerable" by the International Union for the Conservation of Nature (I.U.C.N., Wells *et al.* 1983). "Vulnerable" was defined as the status of a species where "... if the causal factors continue to operate, then the species might become endangered in the future ...". Articles on the conservation of freshwater invertebrates in Tasmania since 1983 have recognised the listing but have tended to imply that the species is safer from endangerment than other "vulnerable" species since there are regulations for the number and size of freshwater crayfish to be taken, and the crayfish were reserved in Caroline Creek (Williams 1983, Michaelis 1985). Indeed, Fulton (1987) believed the species to be widespread and common, and that it should not be listed at all. Despite such confidence, many people who regularly fish for the species claim that both the range and maximum size of the species have declined.

A decision was made to undertake a preliminary investigation of the status of the population of *A. gouldi* at Caroline Creek. Since no assessment of the population had been made since the reserve was gazetted, it was considered that such an investigation might assist in the management of the reserve.

METHODS

Site Description

Caroline Creek is a tributary of the Mersey River, with relatively undisturbed upper reaches flowing into an area used for both forestry practices and agriculture in its lower reaches. The

3 km reserve occurs in the lower reaches, between the Latrobe–Railton road (Tasmap 8115: 497299) and Dawsons Siding road (Tasmap 8115: 506318). White posts mark both extremities of the reserve.

The reserve is composed of three distinct sections. From the downstream boundary, section 1 consists of approximately 300 m of creek surrounded by farmland, with banks dominated by exotic willow (*Salix* sp.) and blackwood (*Acacia melanoxylon*). Section 2, the middle part, extends for 600 m, and occurs in relatively undisturbed vegetation (dominated by *Eucalyptus amygdalina*, *Melaleuca ericifolia* and *Leptospermum lanigerum* with ferns and cutting grass *Gahnia grandis*). Section 3, approximately 2 km in length, occurs upstream and comprises most of the reserve. The creek flows through an exotic pine plantation (*Pinus radiata*) with some *Eucalyptus amygdalina* and *Leptospermum lanigerum* along the banks. The exotic blackberry (*Rubus fructicosus*) is a conspicuous component of the riparian vegetation in each section.

Sections 2 and 3 exhibit canopy vegetation over the creek to provide a high proportion of shading, and additional cover in the form of fallen logs in the creek, particularly in section 2. The habitat might thus be considered to be adequate for *A. gouldi* since these conditions are apparently preferred (Gould 1870, Lynch 1969, Forteath 1985). However, a lower proportion of shading and log cover was found in section 1, corresponding to the occurrence of emergent aquatic plants such as *Typha* sp. Whilst it was not the intention of the study to examine the differences between the number of crayfish in each section, such categorisation of the reserve helps to understand the habitat suitability for crayfish.

Astacopsis gouldi is one of two decapod crustaceans known from the creek system. An undescribed species of *Engaeus* (Horwitz 1986) is found in burrows near the creek. Several species of freshwater fish are known to occur in the creek, namely the sandy (*Pseudaphritis urvillii*), eels (*Anguilla* sp.) and galaxiids (*Galaxias maculatus*) as well as introduced brown and rainbow trout (*Salmo trutta* and *S. gairdneri* respectively).

Sampling Methods

Caroline Creek was sampled between 30 November and 2 December 1987, during which time weather conditions appeared to be optimal for collecting *A. gouldi* (mostly fine, often overcast, cool to mild temperatures, with some light rain falling on the night of the second day). The temperature of the water was measured at 13.5°C on the last day of sampling.

Sampling consisted of placing tangle nets, drop nets and lines, baited with large pieces of fresh fish, at appropriate places (for instance, in deep pools and channels, at the entrance to large crayfish burrows and amongst log jams). A total of 55 sites were baited over the three-day period (8, 15 and 32 bait sites in sections 1, 2 and 3 respectively). Approximately one-third of the reserve was sampled each day, with bait in position for at least 3–4 hours during the middle of the day. Nets and some bait lines were left in position overnight. In addition, crayfish were collected downstream of bait sites when they were found beneath logs or rocks or walking on the creek bed.

The locations were noted of all crayfish captured in the reserve. Their size (carapace length, CPL, using vernier calipers to the nearest 0.1 mm) and sex were also recorded. The reproductive condition of females was recorded by observing the setation of the gonopore (Turvey 1980, Morgan 1986) and the presence or absence of eggs. Notes on their external condition (presence of temnocephalanas, hardness and cleanliness of shell) were made and all individuals were given a distinctive mark.

In order to determine whether the reserve was being fished or not, the number and location of bait lines were recorded. They were then removed from the reserve.

RESULTS

Over the three-day period a total of 24 individuals of *A. gouldi* were captured, ranging from 38.6 to 126.6 mm CPL (fig. 1). Four crayfish in the lower part of this size range were seen but could not be captured. No crayfish of legal size (>130 mm CPL) were found and no reproductively active females were found. The largest individual came from section 1, 12 came from section 2, and 11 came from section 3. Of the 24, 15 individuals were collected from baits and the remaining 9 were found under logs or rocks or walking along the stream bed. No marked animals were recaptured.

Seventeen crayfish were found bearing temnocephalans; of these the two largest crayfish bore a large species (resembling *Temnocephala quadricornis*) whilst the remainder bore the small species *T. tasmanica*.

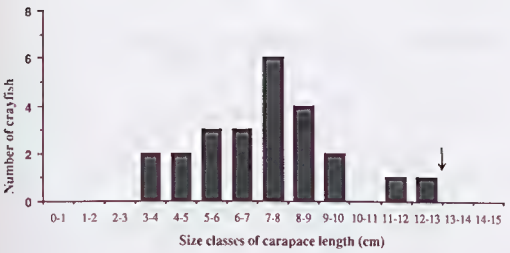

FIG. 1 — Size distribution of crayfish collected from Caroline Creek, presented in size classes of carapace length (CPL). The legal size limit for freshwater crayfish in Tasmania (130 mm) in indicated by an arrow.

Only one crayfish collected was not with a hard exoskeleton, indicating that the majority of specimens were not in an immediately pre- or post-moult condition.

A total of 29 old bait lines were found and removed from throughout the reserve (1, 9 and 19 lines found in sections 1, 2 and 3 respectively).

DISCUSSION

The results suggest that there are few crayfish in the reserve. There are two sources of evidence for this assessment. Firstly, the low number of crayfish collected from what was considered to be suitable habitat. The numbers are very low when compared to other sites sampled in northern Tasmania where the sampling intensity has been equal or less, and where the numbers of crayfish collected were considerably larger. For instance, on the Inglis River, a section of 500 m of suitable habitat was baited at 29 sites over a three-day period in November and December 1985 and 46 animals were collected (Hamr, unpublished data). Secondly, the lack of females either in berry or in reproductive condition, suggests poor recruitment in the reserve itself, and in fact up to 400 m upstream of the reserve where attempts to collect individuals with baited lines met with no success. This assessment is made despite the fact that no recaptures were made. It is considered that there was insufficient time available in the sampling strategy to recapture the marked crayfish.

It is beyond the scope of this paper to determine if, and indeed how, the population has declined since being gazetted. However, some evidence was found, in the form of bait lines, to suggest that the reserve has been subjected to fishing pressure since, and possibly prior to, gazetting of the reserve. Lines ranged from being old and weathered to being recently placed with bait still attached. The absence of legally sized individuals of *A. gouldi* from our collections during this sampling period, supports this suggestion. Since taking of fish in this reserve is illegal (*Regulation 8, Subregulation 1[1], Inland Fisheries Regulations* 1973), our observations suggest that the management of the reserve has been inadequate.

Is is suggested that the current population does not warrant reserve status. This is ironical considering the hope of Lynch (1969) that "... information gained from observations in the study area (Caroline Creek) will provide a basis for the creation ... of larger reserves for the crayfish". However, reserve status should not be removed from the site without implementing complementary action such as gazetting of a new reserve and ensuring its adequate management.

Any new reserve should contain a demonstrably large and thriving population of *A. gouldi* in its natural range, and ideally should be undisturbed by forestry activity, agriculture, mining or the presence of trout and should not have suffered fishing pressure in the past. Some or all of these ideal attributes might be difficult to attain. It is of utmost importance to ensure that fishing is prevented in any new reserve otherwise fishing pressure on the crayfish may increase after gazetting due to the inadvertent advertising of a large population, particularly if accessible to nearby urbanisation. Easy access for road or off-road vehicles should be avoided to discourage illegal fishing. Without adequate protection, any reserved population of *A. gouldi* is at risk from recreational fishermen, as observed at Caroline Creek where reserve status has not prevented illegal exploitation. Given suitable management of the habitat and adequate policing, a new reserve or reserves for *A. gouldi* could be created that would contribute to conservation of the species and removal of the vulnerable status, conferred on the species by the I.U.C.N. (Wells *et al.* 1983).

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REFERENCES

FORTEATH, N., 1985: Studies on the Tasmanian freshwater crayfish *Astacopsis gouldi*. *Tasm. Inld Fish. Commn Newsl.* 14: 5.

FRANCOIS, D.D., 1960: Freshwater crayfishes. *Aust. Mus. Mag.* 13: 217–221.

FULTON, W., 1987: Tasmania's endangered freshwater fauna. *Tasm. Inld Fish. Commn Newsl.* 16(1): 2–3.

GOULD, C., 1870: On the distribution and habits of the large freshwater crayfish (*Astacus* sp.) of the northern rivers of Tasmania. *Proc. R. Soc. Tasm.* (1870): 42–44.

HORWITZ, P., 1986: The systematics and biogeography of the freshwater crayfish genus *Engaeus* Erichson. Unpubl. Ph.D. thesis, Univ. Tasm.

LYNCH, D.D., 1969: Tasmanian giant freshwater crayfish *Astacopsis gouldi* Clark. *Aust. Soc. Limnol. Bull.* 2: 20–21.

MICHAELIS, F.B., 1985: Rare or threatened species from inland waters of Tasmania, Australia. *Rec. Queen Vict. Mus.* 87.

MORGAN, G.J., 1986: Freshwater crayfish of the genus *Euastacus* Clark (Decapoda, Parastacidae) from Victoria. *Mem. Mus. Vict.* 47: 1–57.

SMITH, G.W., 1909: *A NATURALIST IN TASMANIA*. Oxford Clarendon Press, London.

SWAIN, R., RICHARDSON, A.M.M. & HORTLE, M., 1982: Revision of the Tasmanian genus of freshwater crayfish *Astacopsis* Huxley (Decapoda: Parastacidae). *Aust. J. Mar. Freshw. Res.* 33: 699–709.

TURVEY, S.P., 1980: Aspects of the biology of the freshwater crayfish *Euastacus spinifer* (Heller) (Decapoda: Parastacidae). Unpubl. M.Sc. thesis, Univ. Sydney.

WELLS, S.M., PYLE, R.M. & COLLINS, N.M., 1983. *THE INTERNATIONAL UNION FOR THE CONSERVATION OF NATURE INVERTEBRATE RED DATA BOOK*. IUCN, Gland, Switzerland.

WILLIAMS, W.D., 1983: *LIFE IN INLAND WATERS*. Blackwell Scientific Publications, Melbourne.

(accepted 20 May 1988)

LAND USE ON CAPE BARREN ISLAND, TASMANIA

by R. A. Perrin

(with six text-figures)

PERRIN, R.A., 1988 (31:x): Land use on Cape Barren Island. *Pap. Proc. R. Soc. Tasm.* 122(2): 73–83. ISSN 0080–4703. P.O. Box 763, Rockhampton, Queensland, Australia 4700, formerly University of Tasmania, Hobart.

The physical and biological environment of Cape Barren Island is described, the human environment is outlined in terms of past and present patterns of land use, and land use issues are detailed. The island has important biological and historical features, and reservation of certain areas seems warranted. Agricultural developments on the island are severely constrained by the poor soils and isolation from markets, but alternative developments such as aquaculture and wilderness conservation appear feasible. Tasmanian Aboriginals at present claim extensive land rights on the island and the resolution of these claims is necessary if a land management plan for the island is to be successfully implemented.

Key Words: Cape Barren Island, land use, aquaculture, wilderness conservation.

INTRODUCTION

Cape Barren Island lies about 20 km off the northeastern coast of Tasmania and, like many other islands in the Bass Strait region, remains relatively undisturbed. There have been few land use developments on the island, primarily due to its remoteness and poor soils, but with increasing pressure for farmland and tourism destinations this situation is likely to change.

If changes in land use are unplanned, there is a danger that the unique environment and special historical and biological importance of Cape Barren Island will be degraded. There has been a call for the production of a management plan for the island (Allen *et al.* 1978) but this is yet to eventuate.

The aim of this paper is to bring together the basic information on the physical, biological, and human environment of Cape Barren Island and to introduce the options for future land use. It represents the first comprehensive compilation of information on Cape Barren Island, the data being gathered from published and unpublished papers, letters, interviews, and a trip to the island in October 1985.

PHYSICAL ENVIRONMENT

Topography and Climate

Cape Barren Island, located south of Flinders Island, is the second largest island in the Furneaux Group, with an area of 445 km (fig. 1). It is a high, rugged island with a much indented coastline and offers visitors spectacular coastal panoramas. Granite underlies most of the island and in places forms peaks exceeding 500 m in height. The Mount Munro range in the northwest runs east–west across the island for approximately 10 km and culminates in Mount Munro (687 m) (fig. 2). The Mount Kerford range in the southeast runs north–south for approximately 10 km and peaks at Mount Kerford (503 m). Two other significant peaks are Double Peak (512 m) and Hogans Hill (392 m) (Blake 1947).

On the eastern side of the island there is a low-lying coastal plain, from Puncheon Point in the north to Cape Barren in the south, comprising about 20% of the land area. In places sand dunes have altered drainage patterns and formed lagoons which parallel the coast. On the western side there is a slightly elevated undulating plain extending from Sandford Bay on the north coast to Thunder and Lightning Bay on the south coast.

Drainage is mainly via short creeks arising in the high inland areas. Most of the creeks flow either north or south directly to coastal bays via broad low-lying valleys (Pinkard & Richley 1982).

Information on the climate of Cape Barren Island was derived from the records of the Bureau of Meteorology, Hobart. Rainfall data were collected on Cape Barren Island, wind and temperature data at Pats River, Flinders Island.

Cape Barren has a temperate maritime climate. The average annual rainfall is 710 mm and precipitation is greatest in winter (fig. 3). The island experiences generally mild and even temperatures with a maximum in February and a minimum in July. The prevailing wind directions are westerly and northeasterly.

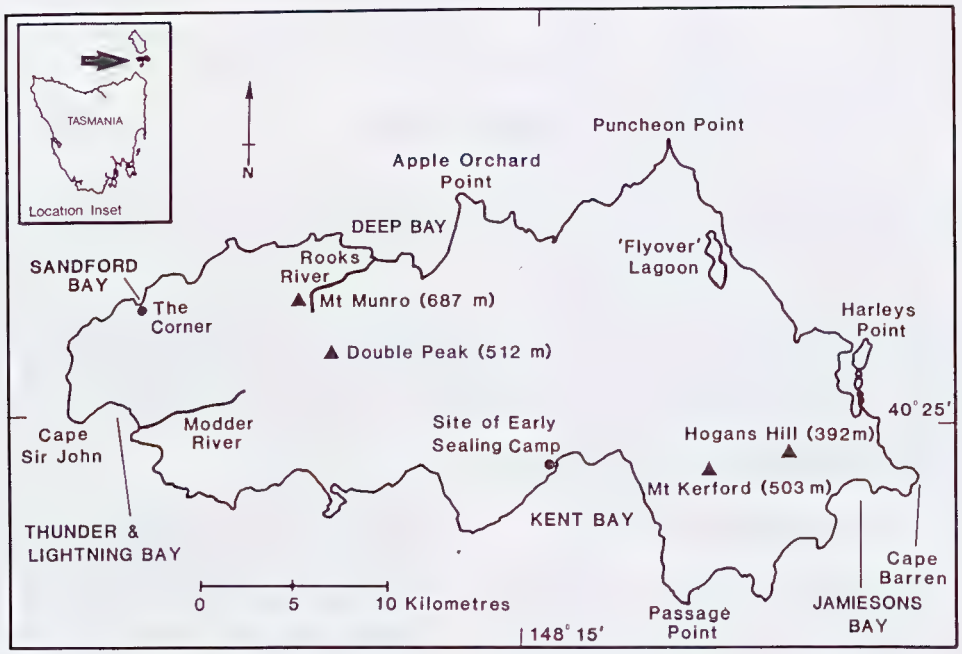

FIG. 1 — Cape Barren Island.

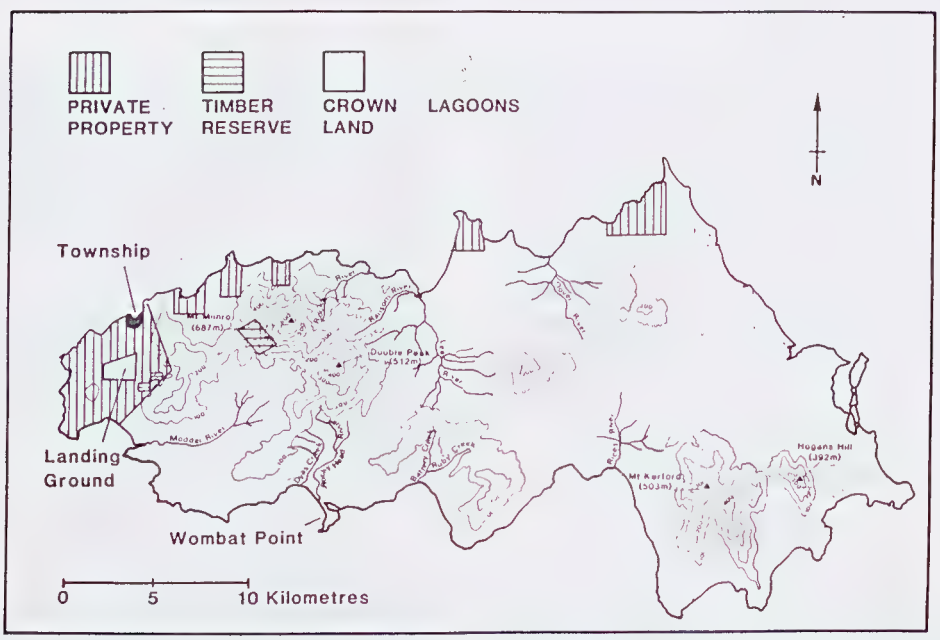

FIG. 2 — Topography and land tenure of Cape Barren Island (after Tasmania 1:100 000 Topographic Map Land Tenure Index Series, edition 2, Flinders Island Special. Lands Department, Hobart, 1983).

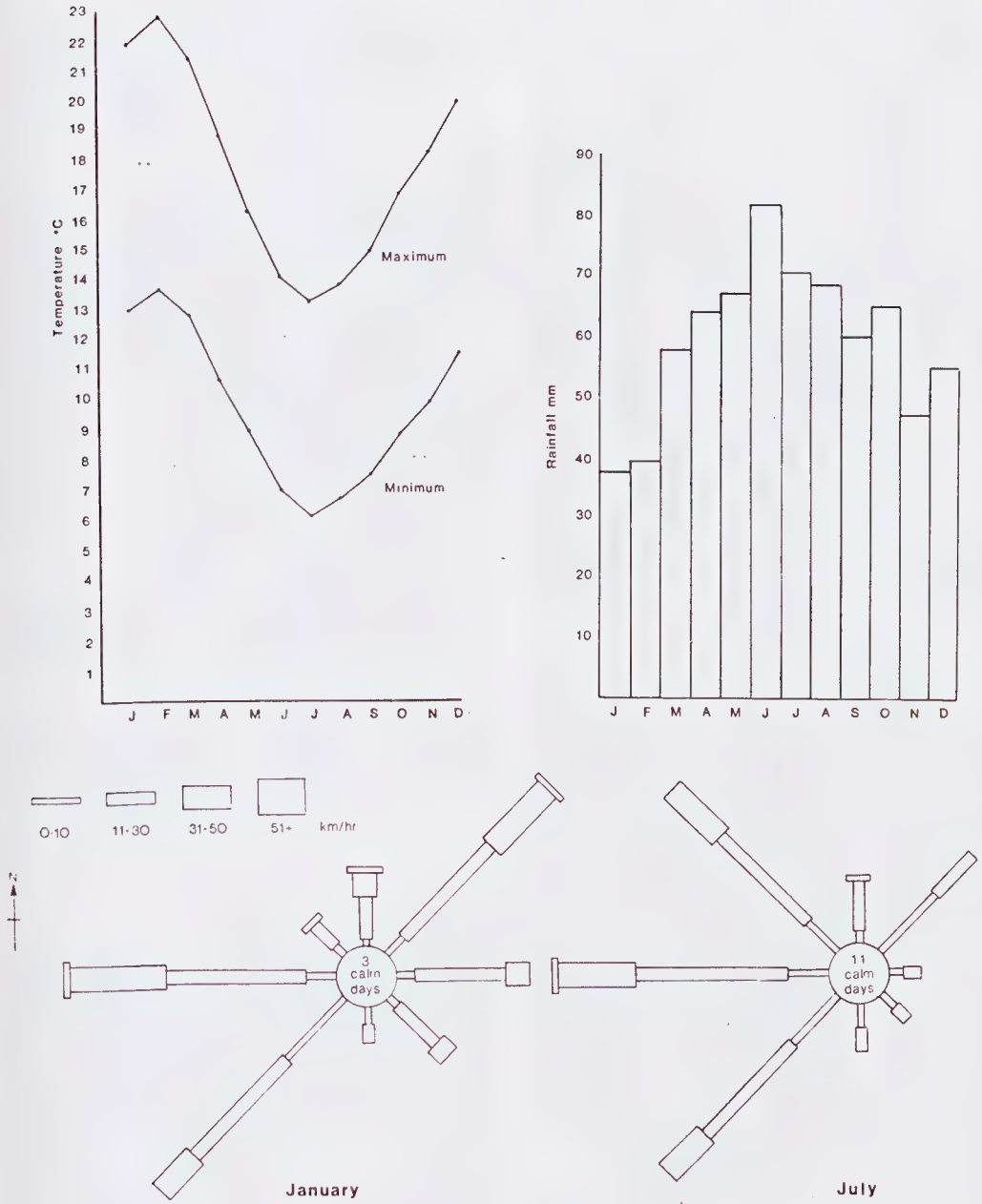

FIG. 3 — Climatic information for Cape Barren Island.

Geology and Minerals

The geology of Cape Barren Island is similar to that of northeastern Tasmania and Wilsons Promontory in Victoria (E.J. Reid, pers. comm.).

The oldest rocks on the island are the Mathinna Beds (metamorphosed, complexly folded beds of sandstones and siltstones) probably of Devonian age, occurring in an east–west tract from Apple Orchard Point on the north coast, towards Harleys Point on the east coast. Shore outcrops occur at Thunder and Lightning Bay in the northwest (fig. 4).

The Mathinna Beds have been intruded by granite and granites now underlie or are exposed over much of the island. Eleven distinct granitoid plutons were recognised by Cocker (1980) on the basis of their mafic mineralogy. In places the granites have been invaded by dolerite dykes.

Tertiary deposits on the island include calcareous sandstones and limestones of Miocene age, notably in the vicinity of The Corner (the island township) and the lowlands of western Cape Barren Island, and fluviatile tin-bearing sediments, occurring most frequently in the low areas of the island. There is a small, isolated outcrop of Tertiary basalt occurring at Lascar Point on western Cape Barren Island (Cocker 1980).

Quaternary sediments on the island consist of aeolian deposits, marine sediments, and alluvium (Goscombe 1965). There are long attenuated sand dunes, oriented in the direction of the prevailing wind in many low-lying coastal areas. Sandy sediments occur over much of the coastal areas of the island. The most recent developments include transverse dunes at Thunder and Lightning Bay and Deep Bay, lunettes on the eastern side of the island, and a 0.3–1 m veneer of alluvium and topsoil which blankets the valleys (Goscombe 1965).

Traces of gold, graphite and molybdenum (Blake 1947), topaz (Cocker 1980), amethyst, garnet, opal, marcasite, rutile and quartz (Matthews 1981) have been identified on the island. Some interest is current in the heavy-mineral content of beach and inland dune sands, in particular zircon, rutile and monazite (for its content of rare-earth minerals) (D. Jennings, pers. comm.).

The only mineral extracted from Cape Barren Island in the past was alluvial tin but poor values, impurities, difficult extraction conditions, and lack of an adequate water supply hampered production. The small scale, the isolation, and the depressed tin markets make tin mining uneconomic at the present time.

Soils

This section is derived from the work of Pinkard & Richley (1982), who, on the bases of topographical, climatic and geological data, divided Cape Barren Island into a series of land systems. The soil descriptions are thus a broad overview of soil types in each of these land systems.

On the eastern, southern, and parts of the western areas of the island the soils are deep with ridges of pale yellow sand, sometimes in the form of low coastal dunes (fig. 5). The sand soil on the flats has an iron organic layer at depth, while the sands on the gently sloping plain are mottled. In the central parts of the island there are large areas of stony and gravelly soils, with rock outcrops occurring frequently. In places the granite soils are overlain by windblown sand. In the Lee River and Dover River areas (fig. 2) there are rock outcrops on the crests and upper slopes. Duplex soils are found on the mid-slopes while clay soils are found on the lowest areas. On the extreme eastern coastal area and at places along the northern coast, deep sand soils have developed. The calcareous sands close to the beaches are undifferentiated and are subject to wave erosion. In the area around Mount Munro mottled duplex soils are encountered. The surface soil is gravelly, while red mottlings are evident at depth, particularly in the soils on the crests and steep upper slopes.

Viewed overall, the island's soils are poorly developed and this has severely constrained agricultural development (P. Warren, pers. comm.).

BIOLOGICAL ENVIRONMENT

Vegetation

The vegetation shares affinities with both the Tasmanian and Australian mainlands and consists largely of coastal heathlands with smaller areas of dry sclerophyll forest and woodland. Many areas have been affected by repeated scrub fires, resulting in an immature vegetation and a predominance of the grasstree (*Xanthorrhoea australis* R. Br.) (Whinray 1977) with an understorey of shrubs and sedges (Kirkpatrick 1977). Significant land clearing has occurred in the vicinity of Puncheon Point, Apple Orchard Point, and on the western side of the island, near The Corner.

In the lowland portions of the island there are large areas of heath (fig. 6). In the drier areas of the lowlands, the larger species are the Smithton

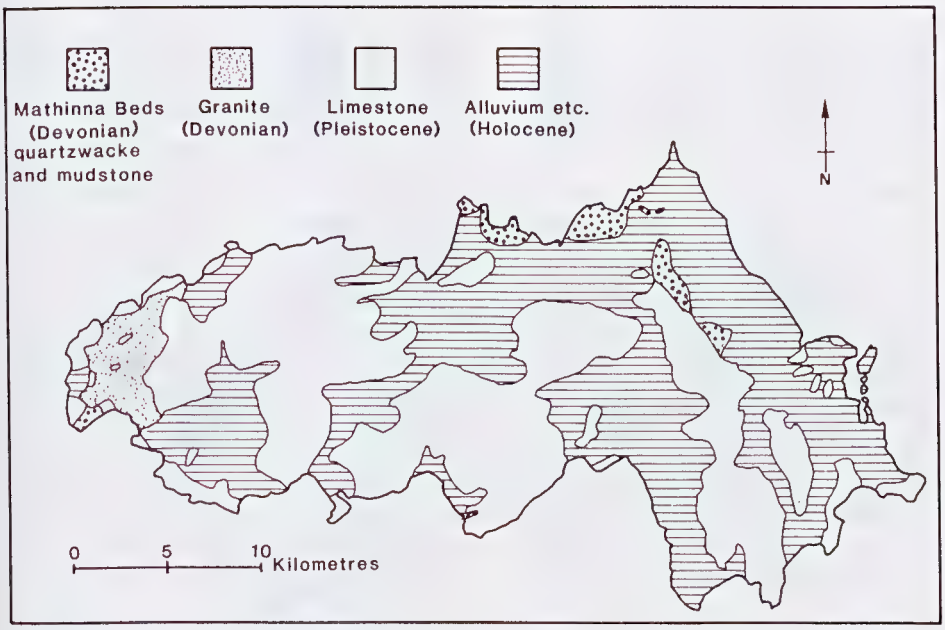

FIG. 4 — Geology of Cape Barren Island (after Geological Map of Tasmania 1:500 000. Department of Mines, Tasmania 1976).

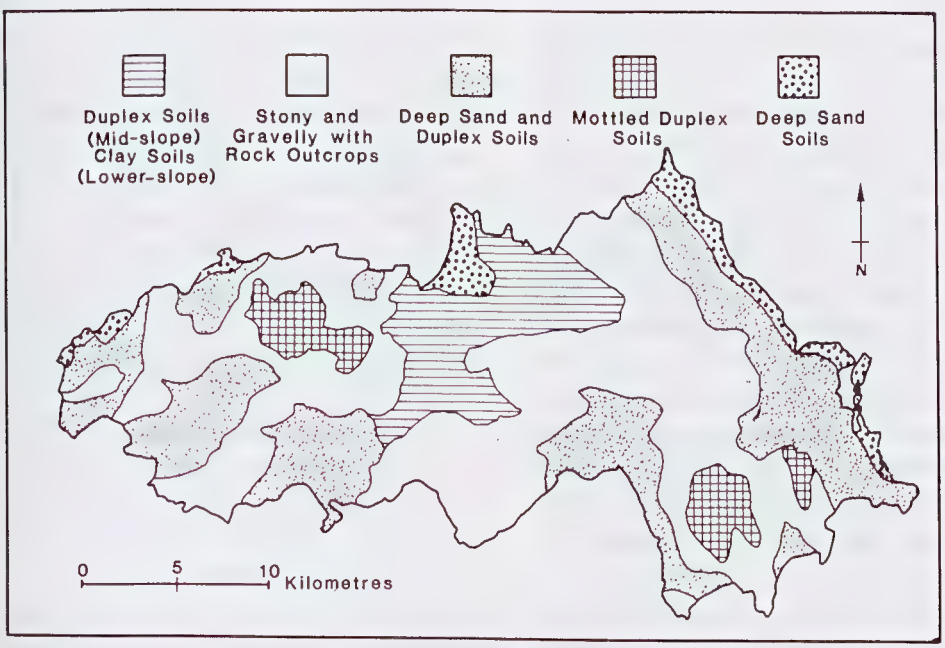
Duplex Soils (Mid-slope) Clay Soils (Lower-slope)
Stony and Gravelly with Rock Outcrops
Deep Sand and Duplex Soils
Mottled Duplex Soils
Deep Sand Soils
N
0 5 10 Kilometres

FIG. 5 — Soils of Cape Barren Island (after Pinkard & Richley 1982).

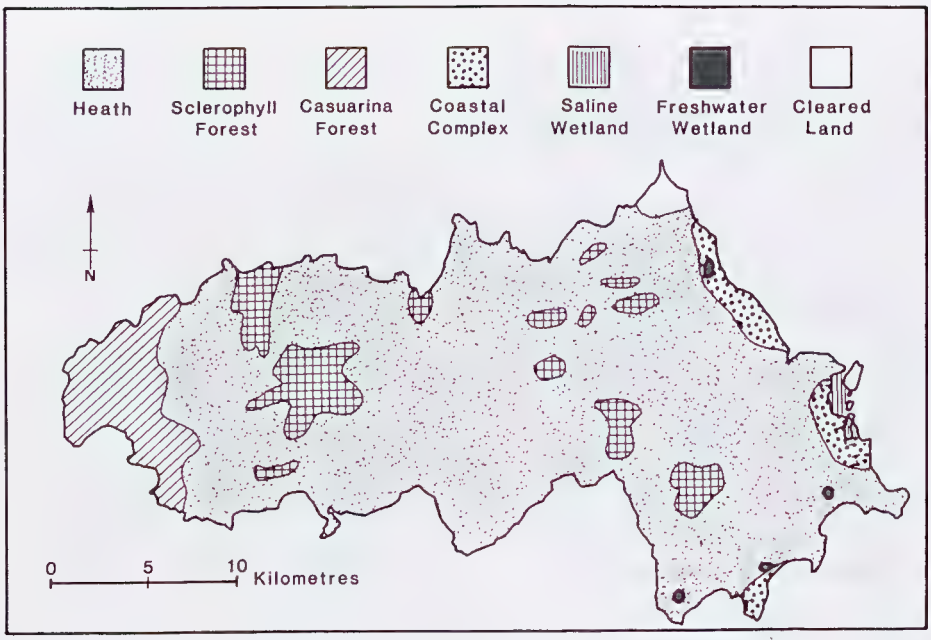

FIG. 6 — Vegetation of Cape Barren Island (after Kirkpatrick & Dickenson 1984).

peppermint (*Eucalyptus nitida* Hook. f.), the grasstree (*Xanthorrhoea australis*), silver banksia (*Banksia marginata* Cav.) and the Tasmanian tea-tree (*Leptospermum glaucescens* S. Schauer). The smaller species in the drier areas include wiry bauera (*Bauera rubioides* Andr.), swamp beardheath (*Leucopogon esquamatus* R. Br.), guinea flower (*Hibbertia procumbens* (Labill.) DC.), and hairy boronia (*Boronia pilosa* var. *laricifolia* Hook. f.). Common herbs in these areas include bogrush (*Schoenus turbinatus* (R. Br.) Poir), climbing sundew (*Drosera planchonii* Hook. f.), and the slender bogrush (*Schoenus tenuissimus* Benth.) (Whinray 1977).

In the wetter areas of the lowlands there are scented paperbarks (*Melaleuca squarrosa* Donn. ex Sm.), swamp paperbarks (*M. ericifolia* Sm.), and manuka (*Leptospermum scoparium* J.R. and G. Forst.). Smaller species include the large-flowered rapier sedge (*Lepidosperma forsythii* A.A. Hamilton) and the pink swampheath (*Sprengelia incarnata* Sm.) (Whinray 1977). There are also a number of herbs in these areas, such as the angled lobelia (*Lobelia alata* Labill.) and the tufted centrolepis (*Centrolepis fascicularis* Labill.) (Whinray 1981).

In the higher areas, such as Mount Munro and Mount Kerford, there are small outcrops of eucalyptus forest, survivors of the frequent scrub fires. These forests contain the manna gum (*Eucalyptus viminalis* Labill.) and the blue gum (*E. globulus* Labill.). The manfern (*Dicksonia antarctica* Labill.), dogwood (*Pomaderris* sp.) and blackwood (*Acacia melanoxylon* R. Br.) are commonly found in the understorey.

Salt marshes are found on the extreme eastern margins of the island. These marshes usually include species such as *Cotula reptans* Benth., *Eryngium vesciculosum* Labill., *Juncus krausii* Hochst., and *Sellieria radicans* Cav. (Kirkpatrick & Glasby 1981).

Cape Barren Island has a number of rare and/or poorly reserved species and communities of plants. The importance of the island's flora is examined in the conservation section.

Fauna

Early reports of visits to the Furneaux Group by naturalists make no mention of Cape Barren Island (Gabriel & Campbell 1894, Le Souef 1929, McKay 1955) and data on its mammals were not

collected until 1969 (Whinray 1971, Hope 1973). Bird data have been collected during short visits to the island (Guiler 1961, Whinray 1970, Abbott 1972, D. Milledge, pers. comm., P. Duckworth, pers. comm., P. Brown, pers. comm.).

Five native mammals have been recorded on the island, and a further four species have been found in fossil deposits. The five extant mammals are the brush wallaby (*Macropus rufogriseus* Desmarest), the pademelon (*Thylogale billardierii* Desmarest), the ringtail possum (*Pseudocheirus peregrinus* Boddaert), the echidna (*Tachyglossus aculeatus* Shaw & Nodder) and the eastern swamp rat (*Rattus lutreolus* Gray). The four mammals recorded from fossil deposits are the potoroo (*Potorous apicalis* Gould), the tiger cat (*Dasyurus maculatus* Kerr), the brown bandicoot (*Isoodon obselus* Shaw & Nodder) and the wombat (*Vombatus ursinus* Shaw). Introduced mammals on the island include the house mouse (*Mus musculus* Linnaeus), ships rat (*Rattus rattus* Linnaeus) and the domestic cat, dog, sheep, cow, horse and goat.

There are 71 bird species recorded from the island (Guiler 1961, Whinray 1970, Abbott 1972, P. Brown, pers. comm., P. Duckworth, pers. comm., D. Milledge, pers. comm.). The Cape Barren Goose (*Cereopsis novae-hollandie* Latham) has been recorded as occurring on the island (Guiler 1961) but not breeding successfully there (G. Hocking, pers. comm.). The occurrence of the tawny-crowned honeyeater on the island is particularly noteworthy as it has a very restricted distribution in Tasmania (P. Brown, pers. comm.).

Collections have been made of land and freshwater snails (Smith & Kershaw 1981), centipedes (Mesibov 1986), spiders, praying mantis and land planarians (R.H. Green, pers. comm.).

Overall, the faunal assemblage, especially the invertebrates, remains poorly studied (R.H. Green, pers. comm.)

HUMAN ENVIRONMENT

Historical Perspective

As yet there is no evidence of pre-European occupation of Cape Barren Island by Aboriginals, although it is known that there were Aboriginals living on Flinders Island approximately 7000 years ago (Orchiston & Glennie 1978). The first documented settlement of Cape Barren Island occurred at Kent Bay (fig. 1) in 1798 with the establishment of the headquarters for an English sealing operation (Cumpston 1973). For a short while it was the third largest settlement in Australia (behind Sydney Cove and Norfolk Island), and it preceded the Risdon Cove settlement in southern Tasmania by four years. It is not clear for how long the Kent Bay settlement was occupied, but seals were still being harvested there in 1810 (Cumpston 1973).

The next phase of settlement on the island was by the descendants of European sealers and their captured Aboriginal "wives"(collectively termed "islanders"). The islanders also inhabited many of the other islands in the Furneaux Group but it seems they were displaced from them when the Government annexed the islands for sale or lease as farmland. Many of these displaced islanders had settled on Cape Barren Island by the 1870's (Murray-Smith 1973). In 1881 the islanders were given exclusive use of (but not title to) a 2400 ha land reserve on the western side of Cape Barren Island (Meston 1947). However, agricultural practices did not develop at this stage, and the islanders relied heavily on hunting mutton birds (*Puffinus tenuirostris* Temminck) for food and income (Allen et al. 1978).

Tin was reported from Cape Barren Island in 1871 and mining commenced at Rooks River (fig. 2) in 1882 (Goscombe 1965). Mining was confined mostly to the Rooks River and Modder River areas and apparently never reached a large scale due to the lack of water for the tin extraction process. Small-scale mining continued in the Rooks River and Modder River areas at least until the mid-1930's.

Further interest in the minerals of the island was shown by large mining companies during the 1960's. In 1965 the Utah Development Company initiated a geological reconnaissance of the Furneaux Group, with particular emphasis on tin extraction in the Rooks and Modder River areas (Volker 1968). In 1968 Broken Hill Proprietary and Utah began a joint offshore drilling programme to explore for tin in Deep Bay (fig. 1). Both of these programmes proved unsuccessful due to low concentrations of tin. In 1972 Blue Metal Industries continued to prospect for tin in the Rooks and Modder River areas but failed to locate tin in commercial concentrations and the programme was abandoned (Standard 1970).

Current Land Ownership and Use

The Department of Lands, Parks and Wildlife has control over most of the 44 500 ha on the island, its areas of control being unallocated Crown Land (35 200 ha), leasehold land (6900 ha) and Coastal Reserve (approximately 100 ha).

The major private holdings of land consist of two farms, one on the extreme western side of the island (the Modder River Station), and the other on the northeastern end of the island, close to Puncheon Point. In addition, there are a number of small farms and residential blocks near The Corner and along the northwestern coast. Of the total island area of 44 500 ha, only 2300 ha (5.2%) are under private ownership. No more Crown Land will be sold, as an embargo was placed on such sales by the Tasmanian Government in July 1985.

The Forestry Commission has a 133 ha timber reserve in the vicinity of Mount Munro, but the reserve is not under active management by the Commission.

No areas are reserved under the *National Parks and Wildlife Act* 1970 on Cape Barren Island but there are some wildlife sanctuaries, nature reserves, and one historic site on some of the small islands near Cape Barren Island. Some reservation under that Act is considered warranted because of the island's heathlands and wetlands and the historic site of the early sealing operations at Kent Bay (P. Bosworth, pers. comm.).

LAND USE ISSUES

Land Rights

Land rights issues date back to the late 1860's when Cape Barren Islanders petitioned the Government to reserve some of the smaller islands in the Furneaux Group for mutton birding (Meston 1947). In 1881, 6000 acres (2430 ha) of land were reserved for the exclusive use of the islanders and in 1912 the Government passed the *Cape Barren Island Reserve Act (Tasmania)* 1912 which gave the islanders an opportunity to each lease 20 ha of land with a 99-year tenure. The Act expired in 1951 and some islanders took out further leases around The Corner township.

Since that time there have been further claims for land rights for Tasmanian Aboriginals which have involved areas of Cape Barren Island. However, the current land rights issue first gained prominence in 1973 as part of a growing national awareness of the rights of Aboriginals (C. Fulton, pers. comm.). The inception of the Tasmanian Aboriginal Centre in 1973 resulted in renewed approaches to Government for the setting aside of areas of Tasmania for Aborigines. In 1977 a petition by Tasmanian Aboriginals for land allocations resulted in the establishment of an Aboriginal Affairs Study Group in April 1978 by the Government (Allen *et al.* 1978). The Study Group recommended that a Lands Trust be set up comprising a committee drawn from Aboriginal organisations in Tasmania. Further, it recommended that all of Cape Barren Island, with the exception of the existing freehold and lease areas, be vested with the proposed Lands Trust and that the rent from existing leases go to the Trust. The Trust would be empowered to grant leases of island land for up to 99 years, preferably to existing Aboriginal residents and with the permission of the Cape Barren Island Council.

The study group also recommended:

> "... that all such leases be granted only in accordance with a general management plan for Cape Barren Island which would preserve the major part of its unique wilderness area of coastal heathland while allowing hunting by accepted practices..." (Allen *et al.* 1978).

None of the recommendations of the Aboriginal Affairs Study Council have been implemented.

Since 1978 a Tasmanian Aboriginal Lands Council Bill has been before Parliament which seeks to vest control of certain lands with a council consisting of adult members of the Tasmanian Aboriginal Centre Inc. Amongst other areas, 35 000 ha on Cape Barren Island are listed for control by the council (Tasmanian Aboriginal Land Council Bill 1987). The Bill specifies that the council shall hold, develop and manage land on behalf of Tasmanian Aboriginals. In particular, the council would have the right to review, cancel or renegotiate any existing Crown leases. Further, the taking of any wildlife from land vested in the council would be legal, for Aboriginals, providing the wildlife is not endangered in terms of the *National Parks and Wildlife Act* 1970.

Obviously this Bill, if implemented, would have far reaching effects on land use patterns on Cape Barren Island. As yet the Bill remains unpassed. Clearly the land rights issue is in need of resolution before long-term land management decisions can be made.

CONSERVATION

Cape Barren Island has been found to contain important vegetation communities and species and, in particular, the extensive heathlands are considered to be areas of high conservation value. The heathlands were examined as part of a Tasmania-wide study which revealed that of the

nine heath communities identified on Cape Barren Island, the dominant community was poorly reserved in State Reserves. It was stated that the conservation of the dominant community was urgent (Kirkpatrick 1977).

In addition, some 200 ha of the island's wetlands were surveyed and were also found to contain species and communities which were unreserved or poorly reserved throughout mainland Tasmania. In particular, five species and two communities were considered in need of reservation (Kirkpatrick & Harwood 1983). Further, 42.3 km were nominated and accepted for inclusion on the list of Wetlands of International Importance Especially as Waterfowl Habitat (WIIEWH), under the Ramsar Convention, to which Australia is a signatory (Blackhall 1986).

In the eastern part of Cape Barren Island there is a large area of Crown Land which has remained unexploited by humans. The vegetation of this area has been degraded by the recurrent scrub fires on the island but contains 12 plant species found on mainland Australia but not on mainland Tasmania, and is thus of considerable biogeographic significance. As well, this area houses the rare bog club moss (*Lycopodium serpentinum* Kunze in Lehm.) and may prove to be the Australia-wide stronghold for this species (Whinray 1977).

In 1979 a survey team reported on wilderness in Tasmania to the Australian Heritage Commission. In its findings the survey team recommended that the "wilderness" area of Cape Barren Island, including offshore rocks and islands, was worthy of protection (Russell *et al.* 1979: 67 *et seq.*).

Studies have been conducted on waterbird habitat on Cape Barren Island as part of a National Parks and Wildlife Service (NPWS — now incorporated into the Department of Lands, Parks, and Wildlife) survey to determine waterbird usage and the conservation significance of selected Tasmanian wetlands. Seven wetlands were visited, resulting in the recommendation that "Flyover" and other lagoons on the eastern side of the island should have a high conservation priority. The study also stated:

> "... It would be highly desirable to reserve the entire coastal complex to Passage Point ... if the Service is unable to do this it is recommended that first priority be given to "Flyover" Lagoon and second to an area from Harleys Point to Jamiesons Bay" (Blackhall 1986).

The NPWS also proposed the reservation of a large area around Kent Bay (the site of early sealing operations) as an Historic Site but the proposal is yet to be accepted (P. Bosworth, pers. comm.).

AGRICULTURAL/INDUSTRIAL DEVELOPMENT

Further expansion of agriculture on Cape Barren Island is severely restricted by poor soil development, isolation from markets and a high fire frequency. There remain some unused areas of reasonable grazing land (S. Fuglsang, pers. comm.), but, in the present economic climate, these would allow at most only a few more small farms to become established.

An assessment of the forestry potential of Cape Barren Island was made in 1975 by the Commonwealth Department of Aboriginal Affairs and the Tasmanian Forestry Commission. It was concluded that plantation forestry would be uneconomic in the long term due to the inadequate soil depth and drainage, low soil fertility and rainfall, high salt spray and sea winds, risks of fire, lack of expertise on the island, poor road infrastructure, and isolation from markets (R.N. Parker, pers. comm.). Since this study was made, these factors have changed little and forestry still appears to be uneconomical.

Preliminary investigations into the suitability of the island for aquaculture ventures involved the growing of Pacific oysters (*Crassostrea gigas* Thunberg) and blue mussels (*Mytilus edulis* planulatis L.) in the vicinity of The Corner, but the results were inconclusive (D. Wolfe, pers. comm.). However, the aquaculture potential of Cape Barren Island appears to be considerable. There are many bays, inlets and rivers that are likely to be suited for the culturing of species such as oysters, mussels, abalone, scallops and freshwater crustaceans. The low pollution levels of marine and freshwater habitats are an important economic asset for the island, especially as such habitats become scarcer elsewhere in Tasmania.

There has been some interest shown recently in the mining of beach and inland dune sands on the east coast of Cape Barren Island. The Ytrium Corporation Pty Ltd has applied for an exploration licence to prospect for heavy minerals used in superconductors. At the time of writing no licence had been issued. The proposed area of exploration includes important heath and wetland communities (Kirkpatrick 1977, Kirkpatrick & Harwood 1983) and areas registered on the list of WIIEWH (Blackhall 1986).

In the short to medium term, prospects for oil and gas developments in the immediate offshore areas of Cape Barren Island are considered low (P.W. Baillie, pers. comm.).

Although no formal tourist statistics are kept, it is known that about 500 people visit the island during the period October–April each year. They normally arrive by boat or light plane and are self-sufficient as no accommodation exists for tourists on the island (G. Lloyd-Webb, pers. comm.). In a recent study of tourism in the north and northeast of Tasmania, the development of a wilderness lodge was proposed for either southern Flinders Island or Cape Barren Island in the vicinity of Puncheon Point (fig. 1). The study recognised that development constraints on the Cape Barren Island site included indecision on the future management of the island, high costs of construction and maintenance, low water availability, and the shortage of suitable land (Hepper et al. 1987).

Cape Barren Island offers areas suitable for outdoor recreational pursuits such as wilderness trekking or diving-fishing tours. As wilderness areas diminish in Tasmania the potential for recreation based on the Cape Barren Island wilderness increases.

COMMENTS AND CONCLUSIONS

Future land use decisions affecting Cape Barren Island need to take into account a number of important environmental and ethnological features. The island retains significant areas of wilderness (if somewhat fire degraded), a rapidly diminishing resource in Tasmania. In addition, it has historic and current cultural importance, being the homeland of many of today's Tasmanian Aboriginals.

Little information exists on the island's natural history, but what is known shows that the island has several rare or endangered species or communities. Clearly, more research into the flora and fauna of the island is needed to document these various communities, prior to any major changes in land use.

The mining of beach and inland dunes of Cape Barren Island would threaten important vegetation and faunal assemblages. As well it would destabilise sand dunes resulting in irreversible damage to wilderness and farmland areas. An examination of the impact of mining, via a comprehensive environmental impact statement, seems warranted.

Cape Barren Island offers wide scope for the establishment of a conservation/wilderness area. Such an area would aid the protection of the rare and endangered flora and fauna of the island, and would help meet Australia's international commitments to the Ramsar Convention on Conservation of Wetlands. Further, protection of the area around the sealing site at Kent Bay should be fostered, as this site is of great historic importance.

Agricultural developments, such as forestry and cattle and sheep grazing, are unlikely to expand greatly due to poor soils and the isolation of the island from markets. There needs to be a comprehensive feasibility study of aquaculture around Cape Barren Island.

The resolution of the Aboriginal land rights claim for the unallocated Crown Land on the island is complex and beyond the scope of this paper. Clearly, however, the issue must be resolved if a long-term management plan for the island is to be successfully formulated.

Already many tourists have been attracted to the island. It seems that the special qualities of the island, primarily its wilderness areas and isolation, are major tourism assets which so far remain underexploited. The dearth of information relating to the island has contributed to its unofficial "undiscovered" status, but this will change as the pressures increase for new recreational opportunities.

Finally, a major threat to any future developments on Cape Barren Island is the frequency of fires. Protection of homes, properties and Crown Land from the persistent fires is of major concern.

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REFERENCES

ABBOTT, I., 1972: Birds of Bass Strait. *Pap. Proc. R. Soc. Tasm.* 85: 197-215.

ALLEN, M.D., WHITE, P.W., JACOBS, A.R., JESSUP, H.J. & NICHOLAS, A.I., 1978: Report of the Aboriginal Affairs Study Group of Tasmania. *Tasm. Parl. J. Pap.* 199(2): 1–52.

BLACKHALL, S.A., 1986: A survey to determine waterbird usage and conservation significance of selected Tasmanian wetlands. Occ. P*ap. Tasm. Natl Pks Wildl. Serv.* 14: 1–110.

BLAKE, F., 1947: The Furneaux group of islands. Unpubl. Rep. Dep. Mines Tasm.

COCKER, J.D., 1980: Regional geology of the Southern Furneaux Group. *Pap. Proc. R. Soc. Tasm.* 114: 49–67.

CUMPSTON, J.S., 1973: FIRST VISITORS TO BASS STRAIT. *Roebuck Soc. Publication* 7: 1–103.

GABRIEL, J. & CAMPBELL, A.J., 1894: Report of expedition to Furneaux Group. *Vict. Nat.*, 10: 179–184.

GOSCOMBE, P.W., 1965: Report on a geological reconnaissance of Cape Barren Island with proposals for drilling stanniferous leads. Unpubl. Rep. Utah Development Company, Melbourne 133: 1–16.

GUILER, E., 1961: The 1958–60 Cape Barren goose aerial survey. *Emu* 61: 197–215.

HEPPER, J., BERESFORD, D., BOWMAN, S. & RIEDER, L., 1987: *TOURISM STUDY NORTH AND NORTHEAST TASMANIA*. Government Printer, Hobart: 1–321.

HOPE, J.H., 1973: Mammals of the Bass Strait islands. *Proc. R. Soc. Vict.* 85: 163–195.

KIRKPATRICK, J.B., 1977: *THE DISAPPEARING HEATH*. Tasmanian Conservation Trust Inc., Hobart: 1–95.

KIRKPATRICK, J.B. & DICKENSON, K.J.M., 1984: *VEGETATION OF TASMANIA*. Forestry Commission, Hobart.

KIRKPATRICK, J.B. & GLASBY, J., 1981: Salt marshes in Tasmania: distribution, community composition, and conservation. *Occ. Pap. Univ. Tasm. Geog.* 8: 1–62.

KIRKPATRICK, J.B. & HARWOOD, C.E., 1983: Conservation of Tasmanian macrophytic wetland vegetation. *Pap. Proc. R. Soc. Tasm.* 117: 5–20.

LE SOUEF, A.S., 1929: Notes on some mammals from Bass Strait islands, including a new subspecies of *Pseudochirus*. *Aust. Zool.* 5: 329–332.

McKAY, R.D., 1955: Notes on a collection of reptiles and amphibians from the Furneaux Islands, Bass Strait. *Aust. Zool.* 12: 160–164.

MATTHEWS, W.L., 1981: *OCCURRENCES OF GEMSTONE MINERALS IN TASMANIA*. Department of Mines, Tasmania: 1–16.

MESIBOV, D., 1986: *A GUIDE TO TASMANIAN CENTIPEDES*. D. Mesibov: 1–64.

MESTON, A.L., 1947: The halfcastes of the Furneaux Group. *Rec. Queen Vict. Mus.* ii(1): 47–52.

MURRAY-SMITH, S., 1973: Beyond the pale, the islander community of Bass Strait in the nineteenth century. *Tasm. Hist. Res. Assoc. Pap. Proc.* 20(4): 167–200.

ORCHISTON, D.W. & GLENNIE, R.C., 1978: Residual Holocene populations in Bassiania: Aboriginal man at Palana, northern Flinders Island. *Aust. Archaeol.* 8: 127–141.

PINKARD, G.J. & RICHLEY, L.R., 1982: *LAND SCHEMES OF TASMANIA, REGION 2*. Tasmanian Government Printer, Hobart: 1–66.

RUSSELL, J.A., MATHEWS, J.H. & JONES, R., 1979: Wilderness in Tasmania, a report to the Australian Heritage Commission. *Occ. Pap. Univ. Tasm. Env. Stud.* 10: 1–103.

SMITH, B.J. & KERSHAW, R.C., 1981: *TASMANIAN LAND AND FRESHWATER MOLLUSCS*. Fauna of Tasmania Handbook No.5, University of Tasmania.

STANDARD, J.C., 1970: Geological evaluation of offshore drilling for tin, north east Tasmania and Cape Barren Island. Unpubl. Rep. Blue Metal Industries Mining, EL18/70 and 19/70.

VOLKER, J., 1968: Report on offshore drilling, Tasmania. Unpubl. Rep. 583, Utah Development Company-Broken Hill Proprietary, Melbourne.

WHINRAY, J.S., 1970: List of birds of Cape Barren Island, Furneaux Group, Tasmania. *Tasm. Nat.* 23: 1–2.

WHINRAY, J.S., 1971: The present distribution of some mammals in the Furneaux Group, Bass Strait, Tasmania. *Vict. Nat.* 88: 279–285.

WHINRAY, J.S., 1977: Some plant records for the Cape Barren Wilderness Area. *Tasm. Nat.* 51: 9–13.

WHINRAY, J.S., 1981: An extra plant record for Tasmania. *Vict. Nat* 98: 80–81.

(accepted 31 March 1988)

THE HYDROLOGICAL IMPACT OF THE PARANGANA DAM ON THE MERSEY RIVER, TASMANIA

by A. D. Knighton

(with five tables and six text-figures)

KNIGHTON, A.D., 1988 (31:x): The hydrological impact of the Paranagana Dam on the Mersey River, Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 85–96. ISSN 0080-4703. University of Sheffield, Sheffield S10 2TN, England.

By diverting the waters of the Mersey River into a neighbouring basin, the Parangana Dam changed the hydrological character of the downstream river. The flow records of three gauging stations, located at 10, 67 and 88 km below the dam, provide the basis for identifying changes. Intermediate discharges have decreased the most and even at the furthest downstream station are 50% lower than before. The flow extremes, at both ends of the scale, have been less affected, and particularly the less frequent discharges which can be augmented by overspill. Indeed the highest flood on record, with a recurrence interval of over 500 years, occurred in the post-dam period. One-day and 30-day minimum flows are markedly lower downstream of the dam, but below the Dasher, the main tributary of the Mersey, they seem to recover and have almost regained pre-dam levels by the mouth. The entry of unregulated tributaries in the middle section separates a much changed upstream hydrology from a downstream one able to mitigate the worst effects of the dam except at intermediate discharges. In the upstream part, the physical, chemical and biological character of the river could be adversely affected by the altered flow regime, particularly in those reaches immediately below the dam.

Key Words: Mersey River, Parangana Dam, hydrological effects, Tasmania.

INTRODUCTION

Dams have been built for the purpose of river regulation for more than 4000 years but only in this century has the pace of construction accelerated. 1950–70 has so far been the most significant construction period (Beaumont 1978), although the last decade has seen renewed activity. In North America and Africa up to 20% of total stream runoff is now regulated by reservoirs, with comparable figures for Europe and Asia of 15% and 14% respectively. The Australian figure is more modest at less than 5%, but Tasmania is somewhat of an exception to other states in being rich in water resources.

Dam building for the purpose of power generation has been active there since 1895, with 1964–73 being the decade of maximum expansion. One of the most impressive schemes of that period is the Mersey-Forth Power Development which exploits the potential of the Mersey, Forth and Wilmot rivers in north-central Tasmania (fig.1A). It consists of seven large dams, three major tunnels and seven power stations which generate over 300 000 kW. Its main significance for this study is that it involves the diversion of a major river — the Mersey. Dams are built for a wide variety of purposes but the complete diversion of such a large river is one of the more unusual. In effect, it represents river capture on a large scale.

The Mersey rises at a height of over 1000 m in the glacially deranged drainage of the Central Plateau where annual rainfall totals exceed 2000 mm (fig. 1A). Its profile down to the Parangana Dam is typical of many glaciated valleys, in that irregular convex steps alternate with poorly developed concave basins. For much of its course the river flows through steep and rugged country where the valley is relatively narrow and steep-sided gorges are not uncommon. One of those provided the site for the Parangana Dam, quartzite, schist, phyllite and slate being the dominant local rock types (Paterson 1971).

Work on the Mersey-Forth Power Development began in 1963 and the Mersey dams were completed in 1968 (Rowallan) and January 1969 (Parangana). Some power is generated at Rowallan but, in conjunction with the dammed headwaters of the Fisher, its main importance lies in storage and flow regulation for the power stations further down the system. Those stations are along the neighbouring River Forth, for the Parangana Dam diverts the flows of the Mersey and Fisher westwards through a 5 km tunnel. The

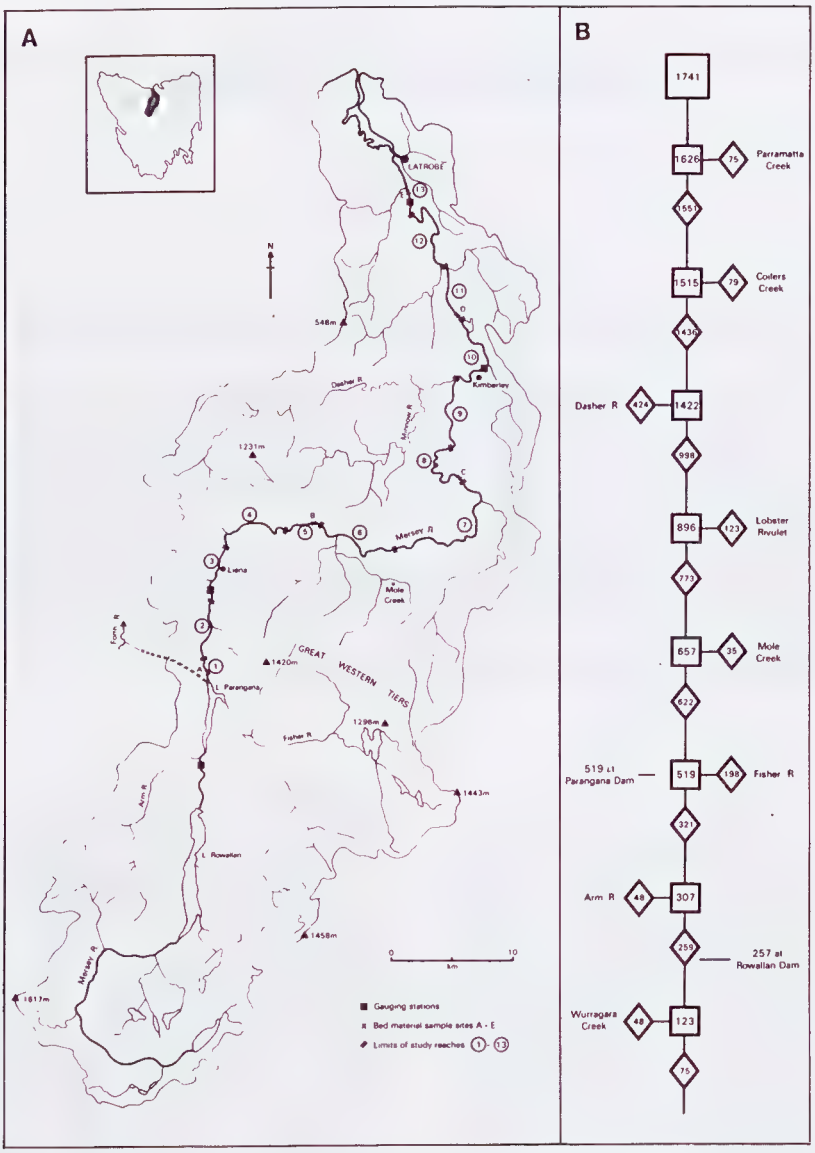

FIG. 1 — (A) The Mersey basin — the inset map shows its position in Tasmania. (B) The tributary structure of the Mersey system expressed in terms of network magnitude. Only the major tributaries are shown.

only discharges immediately downstream of the dam come now from occasional short-term releases and flood flows which exceed the capacity of Lake Parangana.

Reservoirs are known to influence the physical, chemical and biological character of the downstream river (Petts 1984, Lillehammer & Saltveit 1984). Lake Rowallan, for example, has increased iron concentration sufficiently for the iron to be precipitated on the river bed (Tyler & Buckney 1974). In this paper the hydrologic consequences of impoundment are the main concern. Unlike many such studies, this one not only deals with an unusual type of impoundment but also considers the impact along the entire downstream river, a distance of over 90 km. The

downstream propagation of effects is an area of particular uncertainty in the response of rivers to disturbance (Burkham 1981).

CHANGES IN FLOW CONDITIONS

Because of the various conditions for which dams are built and because each dam has its own release policy, *a priori* generalisations about the likely effects of a particular dam are difficult to make. A study of 29 dams in the United States revealed, for example, a wide range of responses as regards mean annual discharge (Williams & Wolman 1984) — three increases, twenty decreases and six cases of no change. However, Petts (1984) has identified the most common consequences of impoundment — reduced average annual discharge, reduced seasonal flow variability, altered timing of annual extremes, reduced flood magnitudes, and the imposition of unnatural pulses. Some of these are present along the Mersey but not necessarily in a simple form.

Figure 1B is a diagrammatic representation of the Mersey's tributary structure expressed in terms of magnitude, a topologic property defined as the total number of headwater sources or streams which ultimately feed a given section of river. At the Parangana Dam, a distance of 69 km from source, the river has lost 63% of its height, 41% of its drainage area and 30% of its final magnitude. Considered in terms of magnitude, therefore, flow additions from tributary sources below the dam are quite high and could be sufficient to mitigate the worst effects of the diversion, particularly downstream of the Dasher. However, according to the relationship between median annual flood (Q_2 in $m^3\ s^{-1}$) and drainage area (A_d in km^2) for pre-dam conditions at eight sections in the Mersey and Forth basins:

$$Q_2 = 7.7\ A_d^{0.57} \quad (\hat{\rho} = 0.94) \qquad (1)$$

the potential loss in flow at the damsite is over 300 $m^3\ s^{-1}$, which represents 95% and 76% respectively of the pre-dam median annual flood at the Liena and Kimberley gauging stations.

The downstream river is supplied from two sources other than tributary additions — infrequent controlled releases through a gated flume in the dam wall and uncontrolled overspills down an ungated spillway. The first are mainly intended to supplement very low discharges so that municipal, irrigation and industrial requirements can be met. The second are not directly quantifiable, but the fact that the potential loss calculated above is not realised at either Liena or Kimberley (table 1) suggests that they do make a large contribution during peak flow conditions. Certainly there was considerable overspill during the 1970 flood which devastated the Mersey valley.

This study is concerned with possible changes to both average and extreme flow conditions. It is based largely on the records of three gauging stations — Liena (1951–83), Kimberley (1945–83) and Latrobe (1963–77, 1982–83) — which respectively lie at distances of 10, 67 and 88 km downstream of the dam, and have lost 94%, 36% and 31% of their natural network magnitude as a result of the diversion. 1969 is taken as the first year in the post-dam period. The years 1965–68 were excluded from the Liena and Kimberley analyses to avoid the risk of dam influence during the construction phase but, because of its shorter record, this was not possible for Latrobe. However, comparing 1965-68 with the other years in the pre-dam period at Liena and Kimberley, changes to the flow regime during construction can be regarded as quite small.

Average Flows

As a result of the flow diversion, mean annual discharge has decreased by 82%, 54% and 48% at Liena, Kimberley and Latrobe respectively, figures which correspond closely to the percentage loss in drainage area at the three stations — 94, 50 and 44. Compared with data for other impoundments (Petts 1984), these levels of reduction are very high, although decreases of 93% and 73% have been recorded 5 km and 112 km below the Conchas Dam on the Canadian River in New Mexico where almost all the water is also diverted (Williams & Wolman 1984).

TABLE 1
Percentage Change in Flood Flows since Dam Closure

Recurrence interval (years)	Gauging station*	
	Liena	Kimberley
1.11	-93	-67 (-66)
2	-73 (-70)	-34 (-38)
5	-39 (-55)	+14 (-13)
10	-4 (-52)	+58 (+5)

* The bracketed figures give the percentage change with the 1970 maximum excluded from the post-dam series.

Flow duration curves based on daily mean flows were constructed to show how the decreases break down at a more detailed scale (fig. 2). Such curves give the percentage of time during which any selected discharge is equalled or exceeded. Thus, the 1% flow is equalled or exceeded 1% of the time (or 0.01 x 365 = 3.65 days per year). The curves suggest that little change has occurred in the magnitudes of the least frequent flows, due partly to the effect of the very large 1970 flood. However, at Liena in particular, the pre- and post-dam curves rapidly diverge and even the 0.1% flow shows a large decrease at that gauge (table 2). The extent of the reduction increases markedly beyond the 5% flow, reaching a maximum for flows in the range of 40–90% duration. Further downstream at Kimberley and Latrobe the maximum decrease is still considerable, in excess of 70% and 60% respectively, but tends to be more concentrated in the middle flow range (table 1). Mean annual discharge (Q_{ma}) has become less not only in magnitude (fig. 3) but also in frequency — its duration has decreased from 33% to 14% at Liena, and from 34% to 26% at Kimberley and Latrobe. Thus, despite its smaller volume the average flow is now exceeded far less frequently. Not surprisingly Kolmogorov-Smirnov tests indicated that the distributions of mean daily flows differed significantly between the pre- and post-dam periods at all three stations.

The distribution of mean monthly discharges was used as the basis for determining whether, in association with the large decreases in daily and annual flow volumes, the seasonal pattern of flow has changed. Taking the pre-dam pattern as indicative of natural conditions, the flow regime was typically temperate oceanic with August as the month of maximum discharge. Interestingly, the monthly flow distribution tended to become more peaked further downstream (fig. 3), suggesting that seasonal contrasts in precipitation and evaporation became more pronounced in that direction.

The Parangana Dam has accentuated the peakedness tendency at all three stations. If the gauging station on the Mersey upstream of the Arm River is used as a standard for comparative purposes (even though it lies downstream of Lake Rowallan), then the regime above the dam has changed little between the two periods apart from a slightly more even distribution throughout the year and a small increase in mean annual discharge, changes which are reversed downstream of the dam (fig. 3). All the gauges have developed a sharply peaked flow pattern, dominated by August, September and July. These months have experienced the smallest decreases in monthly discharge, ranging from 40% at Latrobe to 70% at Liena. In contrast, autumn (especially April and June) and spring have suffered the greatest losses as regards their contribution to the total flow regime. Such changes could affect the ecology of the river quite markedly. Indeed increased growth of freshwater algae has been reported upstream of Liena. Thus the dam has altered not only the magnitude of discharge but also the relative amounts of flow during the water year.

TABLE 2
Percentage Change in Discharge of Various Durations since Dam Closure

Flow duration (%)	Gauging station		
	Liena	Kimberley	Latrobe
0.1	-45	-5	+11
1	-51	-25	-29
5	-65	-45	-35
20	-94	-62	-55
50	-96	-71	-65
80	-96	-67	-61
95	-94	-51	-47

Maximum Flows

Average discharges, be they daily, monthly or annual, can conceal important features of flow behaviour associated with extremes, both high and low. It is not unusual to find that dams have little influence on average daily or annual discharges but significantly decrease annual peaks (table 4, Williams & Wolman 1984, Andrews 1986). The mean annual flood is commonly reduced by more than 25% (Petts 1984).

Flood flows are a particular concern since they represent a potential threat to structures and flood-plain land, and play an important role in the development of river channel form (Knighton 1984). Two modes of analysis are considered, based on series of annual maxima and sequences of high flows. The first uses the maximum instantaneous flow from each year of record to calculate the discharge Q_r with a recurrence interval of T years. In common with flood frequency analyses carried out in Tasmania (Watson 1975, Knighton 1987) and elsewhere (Benson 1968, NERC 1975), the log-Pearson Type III probability distribution was chosen for fitting curves to data

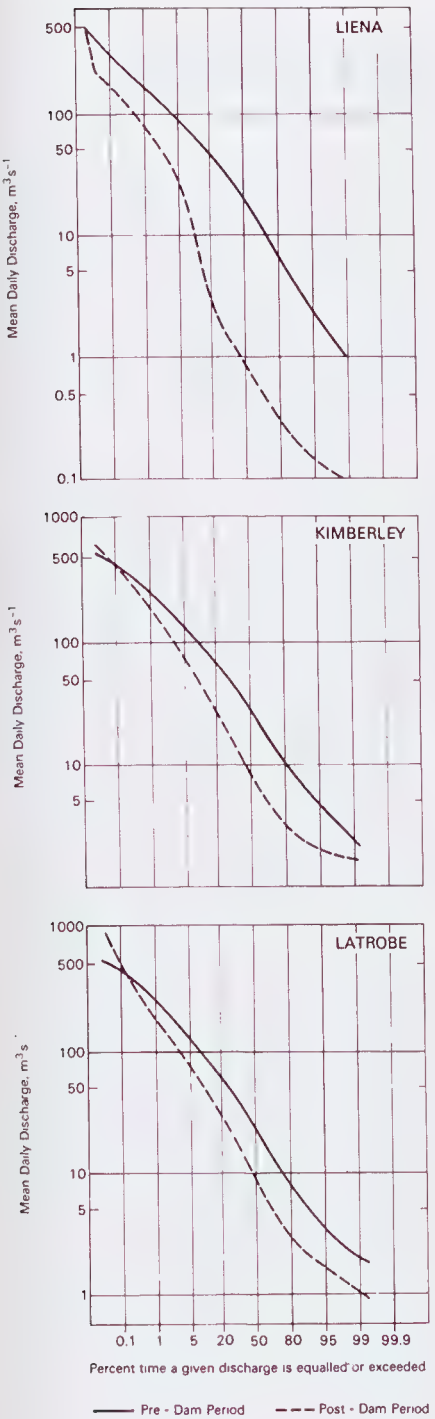
LIENA
KIMBERLEY
LATROBE
Mean Daily Discharge, m³s⁻¹
Percent time a given discharge is equalled or exceeded
0.1 1 5 20 50 80 95 99 99.9
Pre - Dam Period
Post - Dam Period

FIG. 2 — Pre-dam and post-dam flow duration curves for the Liena, Kimberley and Latrobe gauging stations.

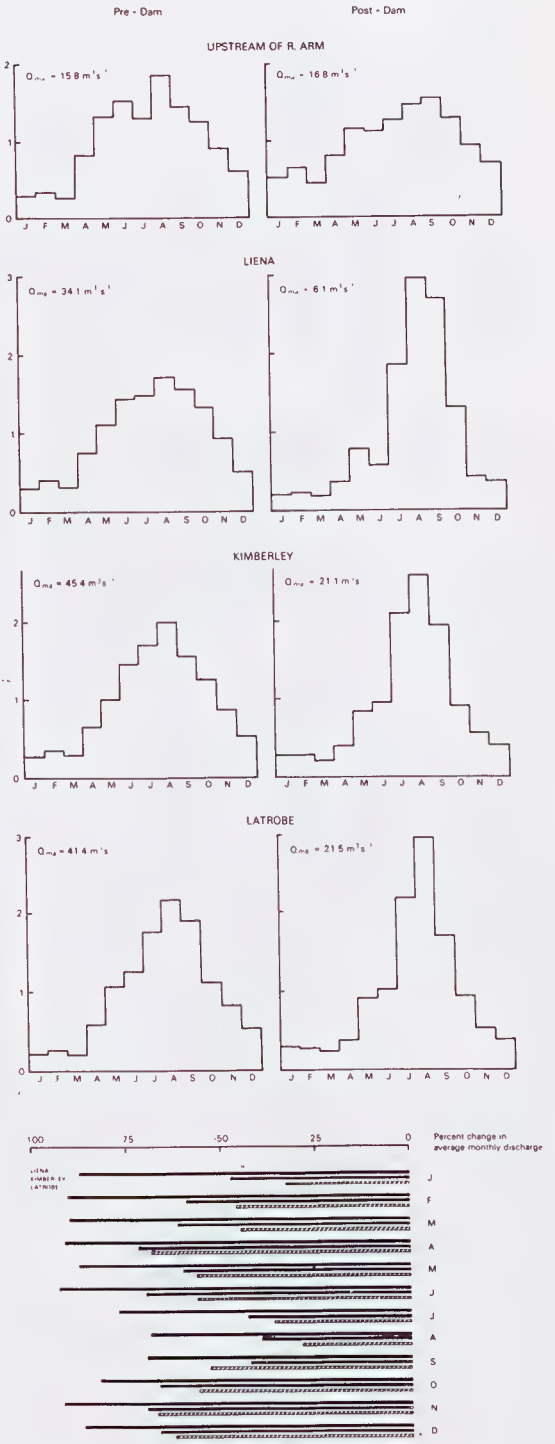

FIG. 3 — Pre-dam and post-dam flow regimes defined in terms of monthly averages; vertical axis gives the ratio to the mean annual discharge (Q_{ma}).

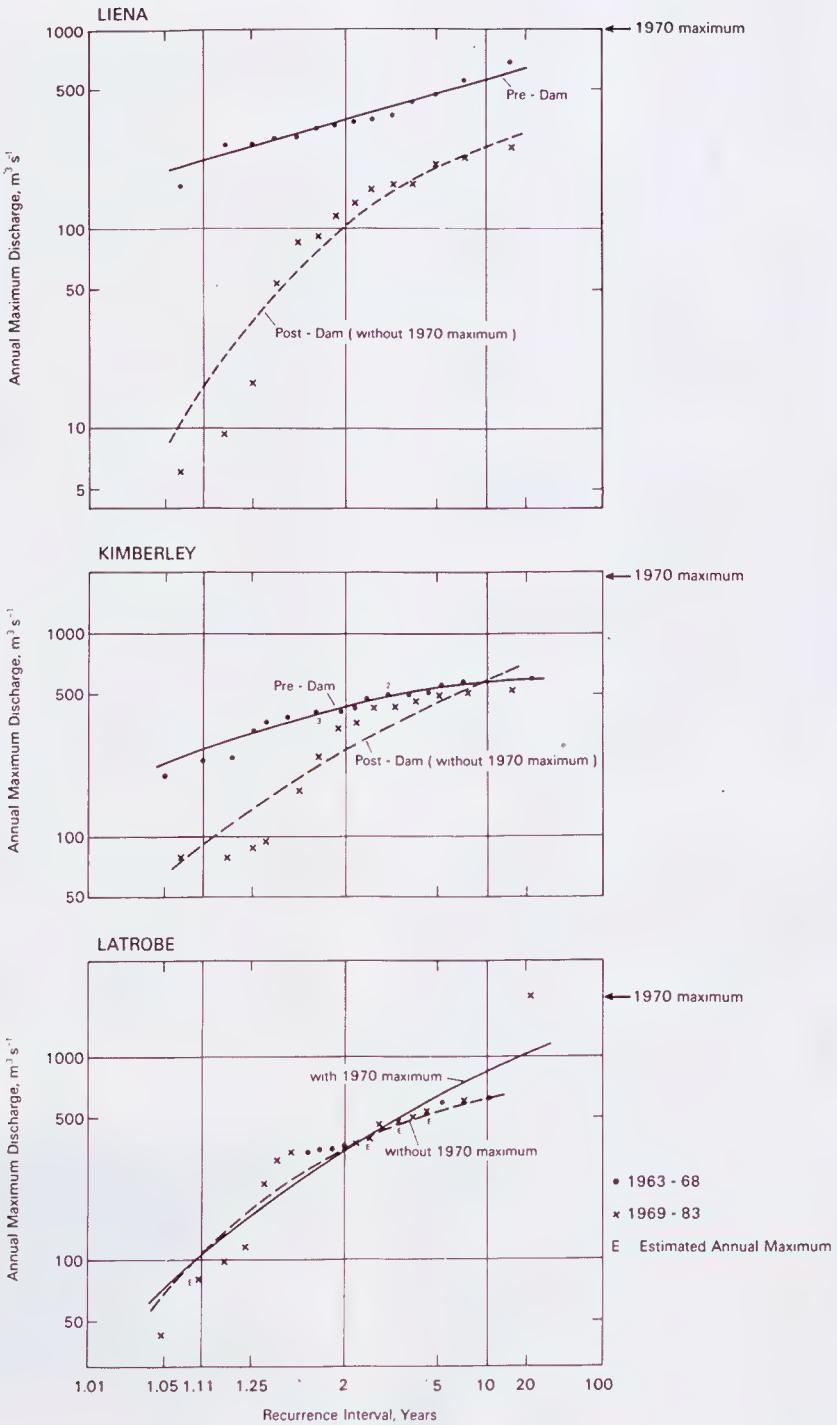

FIG. 4—Flood frequency curves for the Liena, Kimberley and Latrobe gauging stations. The Latrobe data are not analysed in pre-dam and post-dam terms but as a single series.

plots. At Liena and Kimberley the data were split into pre- and post-dam periods for separate analysis but at Latrobe the series was not long enough for such an approach. The data there were treated as a single series.

At Liena the pre-dam data are reasonably well described by a straight line but the post-dam data are distinctly skewed (fig. 4). The greatest difference between the two plots occurs at the lower end of the scale with a decrease in the more frequent flood values of over 90%. Gradually the two series begin to converge but the difference between them beyond Q_2 depends on whether or not the 1970 maximum is included in the analysis (table 2). Despite the dam, that flood exceeded all previous records, fully occupying the spillway. It does not fit easily into the pattern formed by the other peak flows and its recurrence interval is consequently difficult to estimate in a reliable way. If the pre- and post-dam distributions are separately used for estimation purposes, then the flood would have a recurrence interval of 800 years and >1000 years respectively. In an upper level of the Marakoopa Caves, west of Mole Creek (fig. 1A), there is a stalagmite estimated at 9000 years old. In 1970 floodwaters occupied that level and stained the previously white stalagmite to a height of 0.75 m, reinforcing the argument that the 1970 flood was indeed a very rare event. To provide a more realistic picture of the effect of the dam on flood flows, therefore, the 1970 flood was excluded. The resultant plot becomes sub-parallel with the pre-dam distribution beyond Q_5, indicating a 50% reduction of flood magnitudes in the 5–20–year range.

At Kimberley also, the 1970 flood is a long way beyond previous experience, exceeding by 50% the maximum probable flood estimated just one year earlier (Steane 1969). Indeed, extending the curve of a total analysis (1945–83) gave an estimated recurrence interval for that flow of more than 1000 years. Again it is ignored in the post-dam analysis. The plot of points in the post-dam period suggests the possibility of two separate data sets (fig. 4) — a low flood set where the decrease is more than 50%, and an intermediate flood set (recurrence interval >2 years) in which the change from pre-dam conditions is relatively small. The curve for the post-dam period is a poor fit and tends to give a misleading impression of the degree of change, particularly at the ends of the scale (table 1). Nevertheless, it is not uncommon that the smaller, more frequent flood events are the ones to be decreased the most. Larger floods are less influenced by the containing effect of reservoir storage and may therefore be altered only to a negligible extent (Warner 1981).

The data for 1978–81 are missing from the Latrobe record and, in order to provide a complete series for analysis, peaks were estimated from an equation relating annual maxima at Kimberley and Latrobe (correlation coefficent of 0.99). The plot of points suggests that flood conditions have changed relatively little at this downstream station, although all the data in the lowest part of the range belong to the post-dam period (fig. 4). The effect of the dam on annual peaks above the median flood (Q_2) seems to have been largely nullified at 90 km.

Sequences of high flows provide another perspective, where the emphasis is more on maintaining a specified discharge level than attaining a particular discharge magnitude. Here a sequence is defined as the number of days in succession that daily discharge exceeds the 5% flow which, on average, is equalled or exceeded about 18 days each year. It should be remembered that discharge at this flow decreased everywhere along the river after closure of the dam (table 2), so that the comparisons of flow sequences are in any case based on different discharge values.

At Liena there were more than twice as many high flow sequences in the pre-dam period but they were significantly shorter (table 3) with less than 30% greater than 2 days in length. In producing better sustained but less frequent sequences, therefore, the dam seems to have had the effect of making the flow regime less flashy. It should be pointed out, however, that in the post-dam period the number of sequences has decreased dramatic ally after 1975. Of the 277 days on which the 5% flow was exceeded between 1969 and 1983, 236 occurred before 1976. Whatever the reason for that, be it climatic fluctuation or change in release policy, such a trend could have a major impact on the river in those reaches immediately downstream of the dam. Unwanted material is less likely to be flushed out of the system and may begin to concentrate up to deleterious levels.

Kimberley has the same basic pattern as Liena in that the sequence data suggest a flashier regime prior to the dam (table 3). However, the changes are less accentuated, the ameliorating effect of the Dasher being a major factor. Also, the distinction beteen 1969–75 and 1976–83 is less pronounced here. The trend of diminishing effect continues downstream so that by Latrobe pre- and post-dam sequence statistics are virtually identical (table 3).

TABLE 3
Sequences of Days with Discharge above the 5% Flow

	Gauging station					
	Liena		Kimberley		Latrobe	
	pre-dam	post-dam	pre-dam	post-dam	pre-dam	post-dam
Average length of sequence	2.3	4.8	2.1	3.4	3.1	3.2
Number of sequences*	87	39	58	55	57	48

* All data are reduced to a common time base of 10 years.

Minimum Flows

The other end of the flow scale is also important for a variety of reasons — the maintenance of water supplies, water quality, disposal of unwanted substances, and the provision of suitable conditions for fish and waterfowl. As with peak flows, two approaches are used to assess the impact of the dam — frequency analysis of annual minima, and sequences of low flows. The principles of the first are similar to those used above, but with the minimum flow for a given period being selected from each year of record. Two periods were chosen here — 1 day and 30 days. Thus, the 1-day annual minimum is simply the lowest daily mean flow (expressed in $m^3\ s^{-1}$) during the year, while the 30-day annual minimum is the average flow (again expressed in $*m^3\ s^{-1}$) over a 30-day period with the lowest total yield during the year. The second may be a more representative indicator of low-flow conditions, especially as regards water supply.

The curves fit the Liena data reasonably well apart from a few negative residuals at the less reliable upper end of the recurrence scale (fig. 5). The change from pre-dam to post-dam conditions is almost the same for both flow periods (table 4) and represents at least as great a reduction as that produced in the annual maxima (table 1). In view of the contrast before and after 1976 indicated above by the high flow sequence data, a runs test was used to determine whether or not the minima in the post-dam period formed a random sequence or not. Despite a majority of below median values after 1976, neither the 1-day nor the 30-day sequence was significantly different from the random.

The Kimberley curves are even better fits (figure 5) and indicate much smaller decreases than at Liena (table 4). Unexpectedly both sets of curves tend to converge at higher recurrence intervals, indicating that the more extreme minima have been less affected. Of the two flow periods the 30-day one has experienced more change and that may be the one of greater relevance to water management. As at Liena, a runs test indicated no deviation from random in the sequence of post-dam minima.

Insufficent data prevented separate analysis at Latrobe but the distribution of points suggests that pre- and post-dam conditions belong to the same population (fig. 5). The main point to note is that the post-1969 data are better represented at the higher return periods where discharge values are lower.

A low-flow sequence is defined as the number of successive days on which mean daily

TABLE 4
Percentage Change in Annual Minimum Flows since Dam Closure

Recurrence interval, (years)	Gauging station			
	Liena		Kimberley	
	1-day minimum	30-day minimum	1-day minimum	30-day minimum
1.11	-89	-90	-47	-66
2	-93	-93	-31	-52
5	-94	-93	-21	-37
10	-94	-92	-14	-28

discharge fell below the 95% flow given by the appropriate duration curve (fig. 2). The average length of such sequences varies little downstream with the stations having respective values of 9.2, 10.3 and 9.1 days. Rather surprisingly the pre- and post-dam sequence data do not differ significantly in distributional or average properties at any of the gauging stations. The only noteworthy change was the increased frequency of low-flow sequences at Liena (from 15 per 10 years to 30 per 10 years). There is thus a contrast between the high- and low-flow analyses — the dam appears to have had larger impact on the magnitude of low flows (compare tables 1 and 4) but a significant effect on sequencing only in the high flow range.

DISCUSSION AND CONCLUSION

A dam represents a direct and immediate means of disturbing the existing regime of a river. Because of its diversionary role, the Parangana Dam has produced large decreases in almost all flows, the maximum change being in the intermediate flow range. Of the five commonest effects of impoundments listed by Petts (1984), reduced average annual runoff and smaller flood magnitude are the two which have most clearly resulted from the Parangana Dam. Additional effects include lower flow minima, and accentuated seasonal contrasts with the months of highest flow becoming more dominant (fig. 3).

Changes produced by impoundment can be transmitted over considerable distances. Through its effect on the flow regime of the River Nile, the Aswan High Dam has increased erosion potential in coastal areas more than 900 km downstream (Kashef 1981). Data for the Flaming Gorge Dam on the Green River show that, in common with many river regulation schemes, the range of daily mean flows has been significantly reduced and that, despite the entry of major tributaries below the dam, the effect remains substantial 500 km downstream (table 5). However, the data also indicate a progressive diminution of effect with distance at flows above the mean annual.

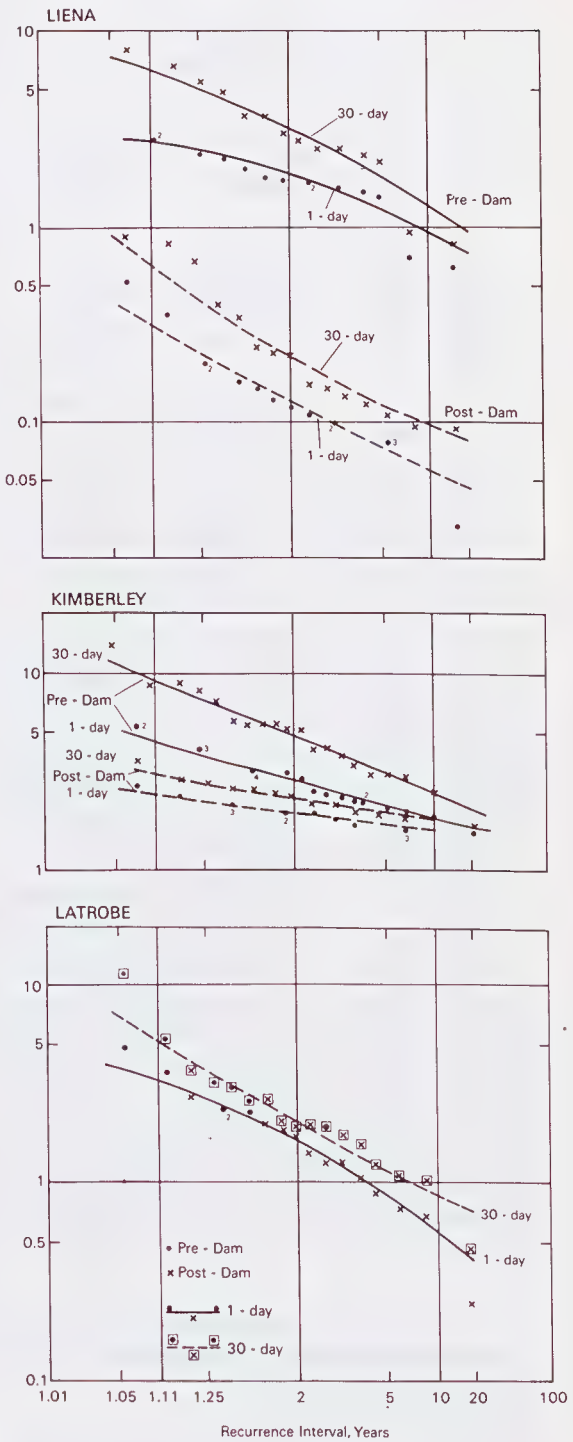

FIG. 5 — Frequency curves for 1-day and 30-day annual minimum discharges at Liena, Kimberley and Latrobe; the Latrobe data are analysed as a single series. Vertical axis is "annual minimum discharge in $m^3 s^{-1}$".

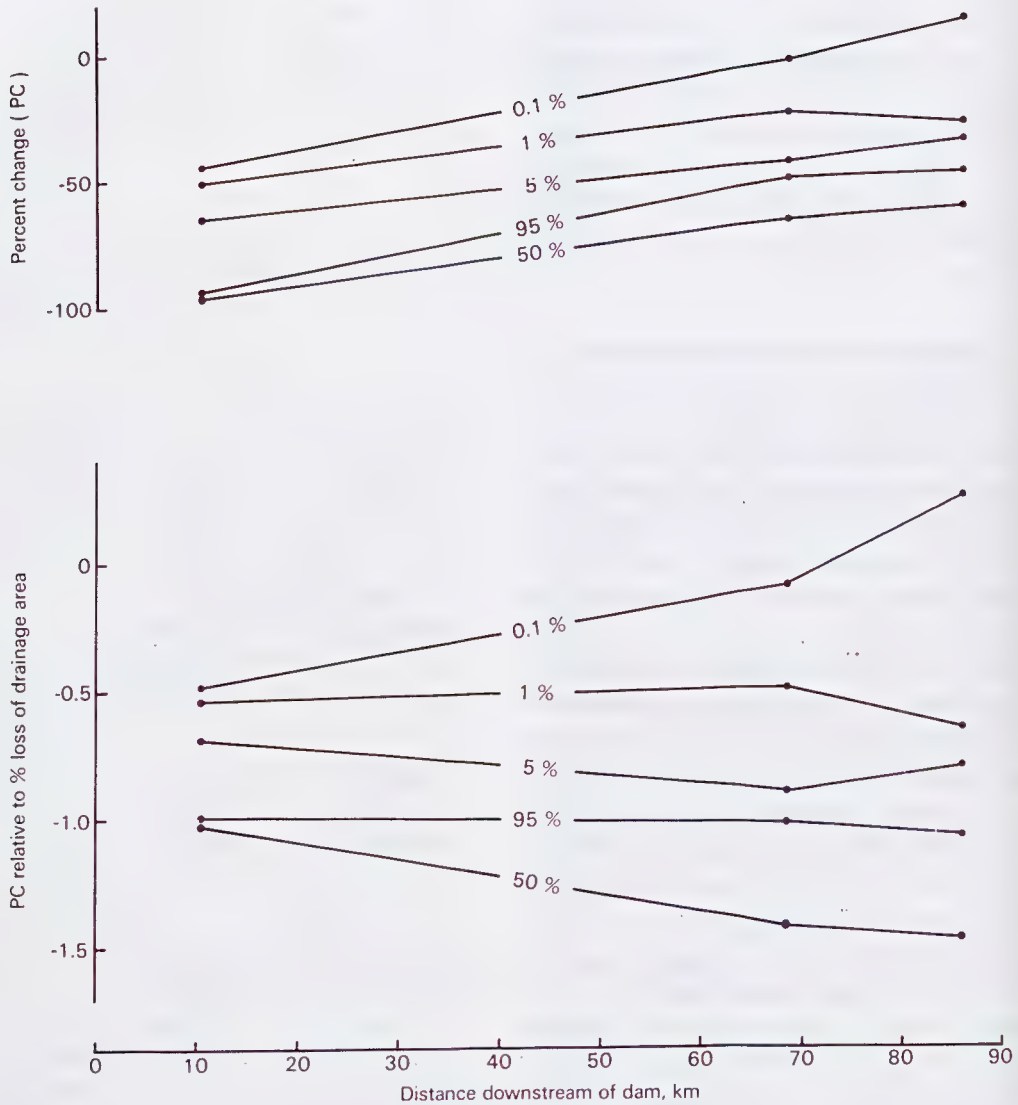

FIG. 6—Percentage change and percentage change per unit loss of drainage area in various flow durations along the Mersey River below the Parangana Dam. The plots refer to flows with a low (0.1%, 1%, 5%), intermediate (50%) or high (95%) duration

TABLE 5
Percentage Change in Flow Conditions Downstream of the Flaming Gorge Reservoir on the Green River, Colorado and Utah (after Andrews 1986)

Flow	Greendale gauge (0+ km downstream)	Jensen gauge (170 km downstream)	Green River gauge (470 km downstream)
1%	-70	-40	-30
5%	-50	-30	-20
Mean annual	0	-3	-4
95%	+85	+120	+75

The Parangana Dam represents an extreme case in that it excludes all but the highest flows from the downstream river. In complete contrast to the Flaming Gorge Dam, the range of daily mean flows has actually increased, due largely to major reductions in intermediate and low-flow discharges (fig. 2, table 2). Not unexpectedly the gauge closest to the dam, at Liena (fig. 1), has experienced the greatest decrease but the effect of the dam on these flows remains large even at Latrobe, 88 km downstream, particularly when the change is expressed relative to the loss in drainage area (fig. 6).

Rather surprisingly in view of one of the major functions of dams, maximum flows have changed the least. Indeed the post-dam period has witnessed the highest flood on record (with a recurrence interval of over 500 years) and it seems that the Parangana Dam is performing only a limited flood control role. As regards the change in peak discharges, two characteristics stand out: the larger, less frequent floods have been the least affected; downstream recovery is much more rapid than for other discharges (fig. 4, table 1) — the more extreme floods may actually have increased in volume further downstream (fig. 6). These characteristics can be attributed firstly, to the role and limited capacity of Lake Parangana which, being a storage reservoir for power generation, is kept at a high level so that there is limited space for accommodating input flows at times of peak runoff; and secondly, to the large runoff contributions from unregulated tributaries below the dam, notably the Dasher (fig. 1). The Mersey is somewhat unusual in having such a large tributary magnitude in the lowest third of its course. That may partly explain why in the pre-dam period the river often peaked at Kimberley before it did at Liena and why on several occasions after 1969 peaks at Kimberley and Latrobe had no equivalents at Liena.

One-day and 30-day minima have been severely reduced by the dam but these low flows do seem to recover reasonably well and by the mouth have almost regained their pre-dam levels. Undoubtedly the contributions from the Dasher and other tributaries are the major factor in the way that minimum as well as maximum flows recover in the lowest parts of the river. Herein lies a contrast, between the lower and upper Mersey, as regards the impact of the dam. In the latter, downstream tributaries compensate to a surprising extent for the diversion of headwater runoff. In the former, and particularly in reaches 1–5 (fig. 1), the decreases in minimum and average flows are so severe that several deleterious effects could ensue. Agricultural wastes may build up and affect the quality of the water. Stagnant pools could become significant breeding grounds for insect populations, especially since flushing discharges are now less frequent at the relevant season and colder headwaters have been diverted. Certainly increased algal growth is a feature of the river above Liena. In function and effect the Parangana Dam is an atypical example of impoundment. Its impact on the physical, chemical and biological character of the Mersey needs to be carefully monitored, since it is far from being fully realised.

ACKNOWLEDGEMENTS

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REFERENCES

ANDREWS, E.D., 1986: Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. *Bull. Geol. Soc. Amer.* 97: 1012–23.

BEAUMONT, P., 1978: Man's impact on river systems: a world-wide view. *Area* 10: 38–41.

BENSON, M.A., 1968: Uniform flood frequency estimating methods for federal agencies. *Water Res. Res.* 4: 891–908.

BURKHAM, D.E., 1981: Uncertainties resulting from changes in river form. *J. Hydraul. Div. Am. Soc. Civ. Eng. 107(5): 593–*610.

KASHEF, A.-A.I., 1981: Technical and ecological impacts of the High Aswan Dam. *J. Hydrol.* 53: 73–84.

KNIGHTON, A.D., 1984: *FLUVIAL FORMS AND PROCESSES*. Arnold, London: 218 pp.

KNIGHTON, A.D., 1987: Streamflow characteristics of north-east Tasmania: I Regional flood flows. *Pap. Proc. R. Soc. Tasm.* 121: 23–33.

LILLEHAMMER, A. & SALTVEIT, S.J. (Eds), 1984: *REGULATED RIVERS. Proceedings of the Second International Symposium on Regulated Streams. Oslo*: 540 pp.

NERC, 1975: *FLOOD STUDIES REPORT*. Natural Environment Research Council, London: 4 volumes.

PATERSON, S.J., 1971: Engineering geology of the Lemonthyme hydro-electric scheme, Tasmania. *Civ. Eng. Trans.*, Institution of Engineers, Australia, April 1971:17–24.

PETTS, G.E., 1984: *IMPOUNDED RIVERS*. Wiley, Chichester: 326 pp.

STEANE, J.D., 1969: The lower Mersey-Forth area and Rubicon River. *Water Res. Surv.*, 11th Report, Rivers and Water Supply Commission, Tasmania: 63 pp.

TYLER, P.A. & BUCKNEY, R.T., 1974: Stratification and biogenic meromixis in Tasmanian reservoirs. *Aust. J. Mar. Freshw. Res.*, 25: 299–313.

WARNER, R.F., 1981: The impacts of dams and weirs on the Hawkesbury-Nepean River system, NSW, Australia. *Paper presented at the 2nd International Conference on Fluvial Sediments*, University of Keele, U.K., 21–25 September 1981.

WATSON, B., 1975: Flood magnitude and frequency Part 1: West Coast of Tasmania, Annual Flood Series. *Hydro-Electric Commission, Investigations Division Report*: 9 pp.

WILLIAMS, G.P. & WOLMAN, M.G., 1984: Downstream effects of dams on alluvial rivers. *U.S.G.S. Prof. Pap.* 1286: 83 pp.

(accepted 12 February 1988)

LABILLARDIERE'S TASMANIAN LICHENS

by D.J. Galloway

(with nine plates)

GALLOWAY, D.J., 1988 (31:x): Labillardière's Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* 122(2): 97–108. ISSN 0080–4703. Department of Botany, British Museum (Natural History), Cromwell Road, London SW7 5BD.

Lichens from T*erra Diemen* (Tasmania) collected in 1792–93 by J.-J. H. Labillardière and now held in the Philip Barker Webb herbarium in Florence (FI–W) number 21 species in 13 genera preserved on 19 herbarium sheets. These include holotype and isotype material of B*aeomyces reteporus* Labill. [= *Cladia retipora* (Labill.) Nyl.], isolectotype material of Stic*ta billardiere* Delise [= *Pseudocyphellaria billardierei* (Delise) Räsänen] and taxa from the following genera: *Baeomyces*, *Cladia*, *Cladonia*, *Hypogymnia*, *Leptogium*, *Menegazzia*, *Parmelia*, *Parmelina*, *Pseudocyphellaria*, *Ramalina*, *Sphaerophorus*, *Stereocaulon* and *Usnea*. These collections constitute the first known lichens from Tasmania. Brief notes, where applicable, accompany the species designations.
Key Words: Labillardière, lichens, Tasmania.

INTRODUCTION

Jacques-Julien Houtou de La Billardière was born in Alencon, Normandy on 28 October 1755 [Chevalier 1953, Carr & Carr 1981 (not 23 October as given in Stafleu 1967:16)]. He abandoned use of his family name Houtou in 1791, subsequently using the shortened surname Labillardière (Carr & Carr 1981). Labillardière studied medicine at Montpellier from 1772 onwards, learning botany there under Antoine Gouan (1733–1821), a friend of Philibert Commerson (1727–73), Boungainville's naturalist on the *La Boudeuse* and *L'Étoile* voyage of 1766–69. His medical studies were completed in Paris in 1780 when he met René Louiche Desfontaines (1750–1833), a life-long friend who was to become Professor of Botany at the Jardin des Plantes. In 1782 Labillardière visited England where he met Joseph Banks and James Edward Smith (Chevalier 1953, Stafleu 1967), both later to be of considerable service to him in 1796 when his Southern Hemisphere plant collections were eventually returned to Paris, after their initial seizure by the Dutch and subsequent capture as a Royal Navy prize (see below). Labillardière studied plants in Syria and Lebanon (including present-day Palestine and Jordan) between 1787 and 1789, his published work on his collections I*cones plantarum Syriae rariorum* being illustrated by Pierre-Joseph Redouté.

With the help and influence of his scientific patron in Paris, Louis Guillaume Le Monnier (1717–99), pupil of de Jussieu and Professor of Botany at the Jardin du Roi (1758–86), Labillardière was appointed one of three naturalists on the ships *La Recherche* and *L'Espérance* under the command of Joseph Antoine Bruni D'Entrecasteaux (1739–93), charged by the Assemblée Constituante on 9 February 1791 to search for the lost expedition of Jean Francois de Galaup, comte de la Pérouse (1741–88). The two ships left France at the end of September 1791 and, after calling at Tenerife and the Cape of Good Hope, made landfalls in Australia including Tasmania (see below). During this time Labillardière made copious botanical collections, many of which he later described (Labillardière 1800, 1807). The fate of the expedition and the deaths of its two senior officers, D'Entrecasteaux and Huon de Kermadec, is amply recounted elsewhere (Stafleu 1967, Carr & Carr 1976, 1981).

After briefly considering Labillardière's collecting sites during his Australian landfalls, and also the subsequent fate of his natural history collections after their capture by the Dutch in Java in 1794, this paper records the lichens collected by Labillardière in Tasmania, now preserved in the Philip Barker Webb Herbarium in Florence. Labillardière has an established place in the annals of Australian and South Pacific lichenology, for his description of *Baeomyces reteporus* (Labillardière 1807), the first published account of an Australian lichen (see Wetmore 1963, Filson 1976, 1986, Kantvilas 1983, Galloway 1985b).

LABILLARDIÈRE'S COLLECTING LOCALITIES

The south coast of Tasmania was first visited by D'Entrecasteaux and his expedition between March and May 1792, after a weary sea voyage from the Cape. Landings were made at "D'Entrecasteaux Bay" and at "North Bay", inlets of Recherche Bay (Nelson 1974, Carr & Carr 1976 and Ducker 1979 give the Tasmanian locality as Storm Bay). Labillardière wrote of the new landscape:

> "It is difficult to express the sensations we felt, at finding ourselves at length sheltered in this solitary harbour at the extremity of the globe, after having been so long driven to and fro in the ocean by the violence of the storms ..." (Labillardière 1800 Vol.I: 158).

There can be no doubt that the country and its natural history as well as the native people made an enormous impact on Labillardière, as a reading of his book shows, and two short extracts capture something of his sense of wonder:

> "In the afternoon I went ashore, accompanied by the gardener and two others of our ship's company, in order to make an excursion into the country towards N.E. We were filled with admiration at the sight of these ancient forests, in which the sound of an axe had never been heard ... The most luxuriant vigour of vegetation is here contrasted with its final dissolution, and presents to the mind a striking picture of the operations of nature, who, left to herself, never destroys but that she may again create" (Labillardière 1800 Vol.I: 170).

The ships spent some 22 days at anchor near Recherche Bay during which time Labillardière and the other naturalists had plenty of opportunities for exploration and collection (Giblin 1928, Nelson 1974, 1975, Carr & Carr 1976). Tasmania was visited again between 24 January and 15 February 1793, Labillardière noting:

> "The whole of the 26th [January] I spent describing and preparing every thing I had collected since our arrival in Rocky Bay. I was astonished at the great variety of productions still afforded me by this part of New Holland, where I had been very diligent in my researches for more than a month the preceding year ... (Labillardière 1800 Vol.II: 13)

> "We had planned a visit to the highest mountains in this part of New Holland, the various sites of which gave us hopes of a great number of new productions ..."

Camping at night in the open Labillardière observed:

> "The air was extremely calm; and about midnight I awakened, when, solitary in the midst of these silent woods, the majesty of which was half disclosed to me by the feeble gleam of the stars, I felt myself penetrated with a sentiment of admiration for the grandeur of nature, which it is beyond my powers to express" (Labillardière 1800 Vol.II: 22–23).

Nelson (1974, 1975) and Carr & Carr (1976) gave further information on Labillardière's collecting sites in Tasmania and at Esperance Bay, Western Australia, and also draw attention to the fact that several of the plants described by Labillardière (1807) could not have been collected on his own travels. These specimens undoubtedly came into his hands from the botanists of the *Géographe* and *Naturaliste* voyage under Nicolas Baudin, one of whom (Leschenault de la Tour) was the presumed collector of *Sticta delisea* Delise [= *Pseudocyphellaria glabra* (J.D. Hook. & Taylor) Dodge] (see Galloway 1988, Galloway & James 1986). Nearly all of the lichens discussed below are from "Terra Dieman" (Tasmania), and it is assumed that they were collected by Labillardière from one of the Tasmanian landfalls of 1792-93, although two putative Labillardière collections from Fée's herbarium may very possibly be from collections made in Esperance Bay, Western Australia. Nelson (1974), Carr & Carr (1976) and Ducker (1979) all gave Storm Bay as the Tasmanian locality corresponding to "Capite van Diemen" of Labillardière's autograph, and published descriptions in the *Specimen*. However, Giblin (1928) mentioned D'Entrecasteaux Bay and North Bay, both inlets of Recherche Bay at the southern end of D'Entrecasteaux Channel and close to South East Cape, while Kantvilas (1983) stated:

> "The localities he [Labillardière] would probably have visited range from Recherche Bay and D'Entrecasteaux Channel to Storm Bay and the Derwent River estuary as far as Glenorchy Rivulet."

THE FATE OF LABILLARDIÈRE'S COLLECTIONS

On leaving Tasmania in 1793, the expedition travelled north via the Santa Cruz and Admiralty Islands to Java. During the voyage both D'Entrecasteaux and his succeeding officer, Huon

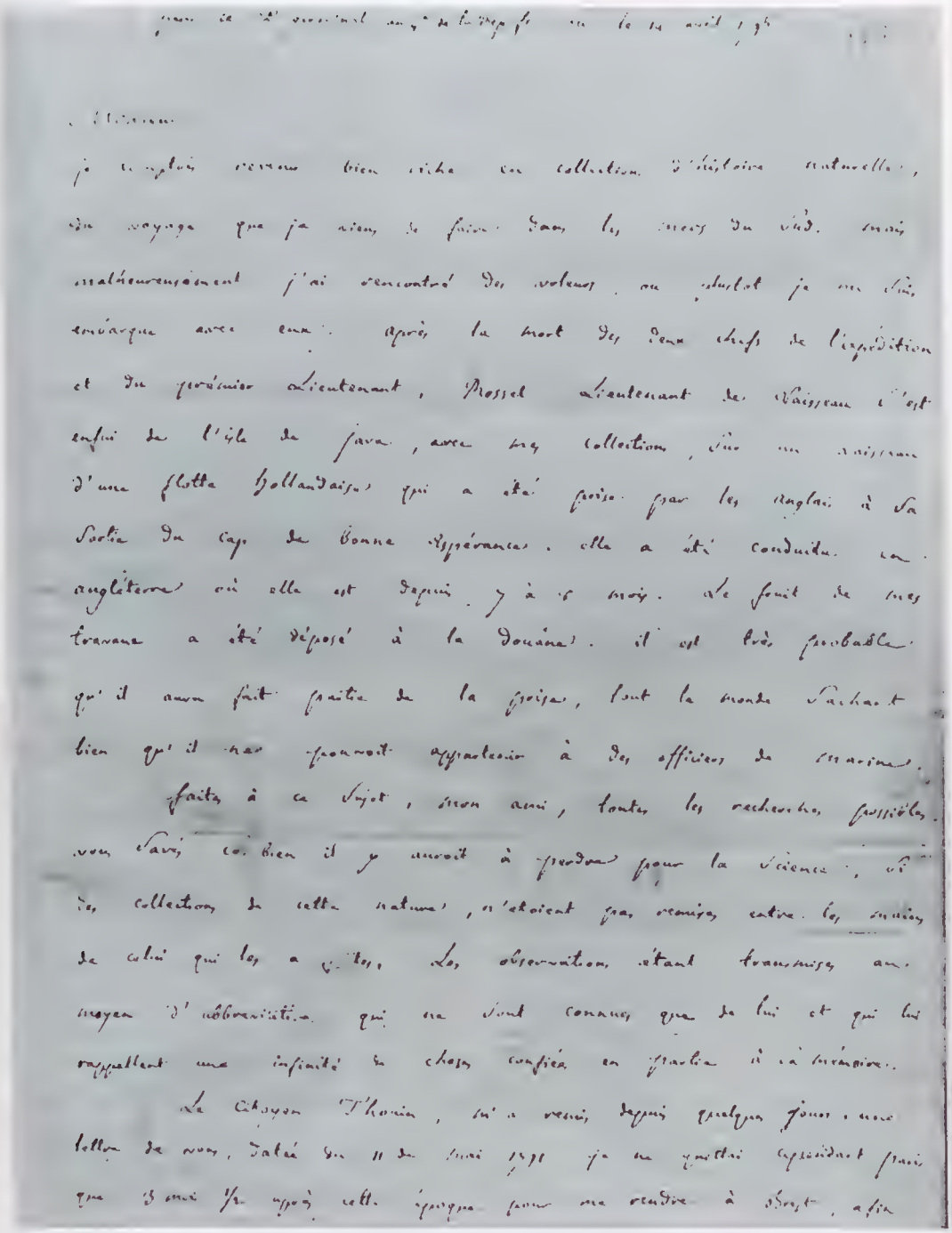

PLATE 1

First page of letter from Labillardière to James Edward Smith, 14 April 1796. Smith Papers (1: 189): Archives, Linnean Society of London.

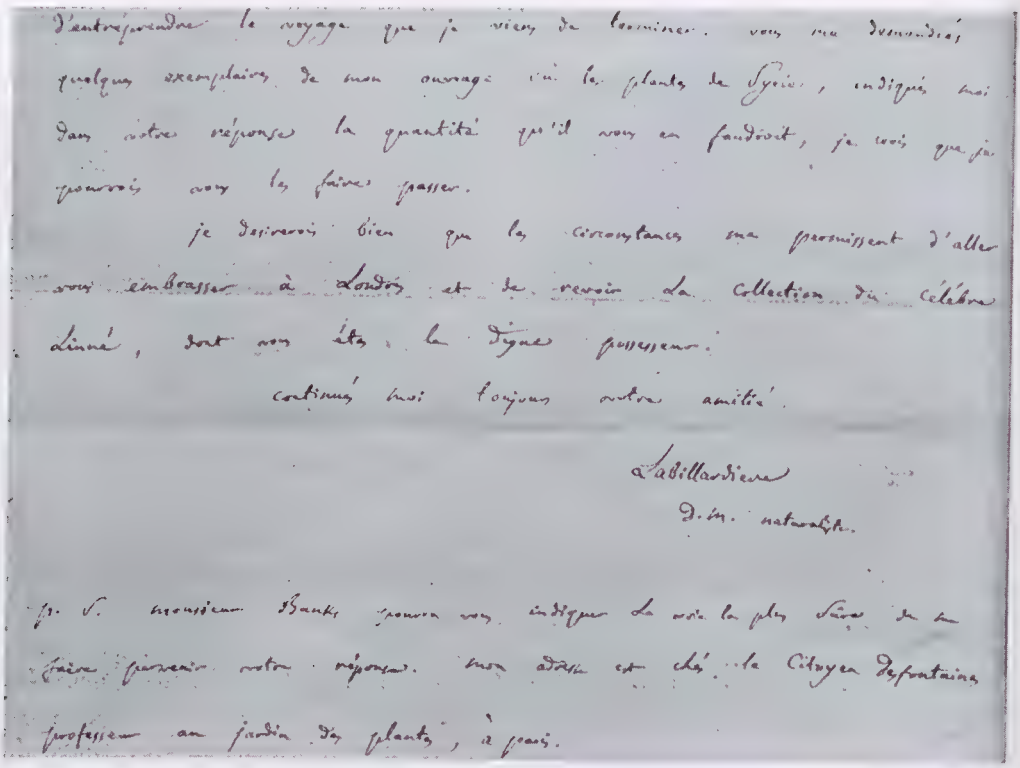

PLATE 2

Second page of letter from Labillardière to JamesEdward Smith, 14 April 1796. Smith Papers (1: 189): Archives, Linnean Society of London.

de Kermadec, died at sea. Command then devolved upon Alexander Hemisvy D'Aribeau who took the ships to Java where they learned of the execution of Louis XVI and of the Dutch being at war with France. Republican members of the ship's company, including Labillardière, were taken prisoner, whilst a number of the Royalist officers under the command of Rossel, who succeeded D'Aribeau on the latter's death, were allowed safe passage to France taking the expedition's (Labillardière's) collections with them (see Nelson 1975, Carr & Carr 1976, 1981). Although losing his collections, Labillardière retained his journal and eventually returned to France in 1796. Meanwhile, in June 1795, the Dutch vessel *Hooghly*, with Rossel and Labillardière's collections aboard, was captured by the British Navy in the Atlantic, 15 days after leaving the Cape. As the British and Dutch were also at war, Labillardière's collections were claimed by the British as a naval prize and taken to London to be lodged in the Customs House.

Although France and Britain were at war, their men of science were not. On Labillardière's return to Paris he wrote to both Sir Joseph Banks and to James Edward Smith (founder of the Linnean Society of London, and then owner of the Linnaeus collection), both of whom he had met in 1782 and corresponded with since, enquiring about the fate of his collections. Labillardière's letter to Smith (plates 1 and 2) is an eloquent plea for the return of the collections to France and to their rightful owner. The praiseworthy role of Sir Joseph Banks in the safe return of the collection to Paris is well documented (De Beer 1952, 1960, Stafleu 1967, Carr & Carr 1981), and Labillardière later (5 March 1800) sent Banks a copy of his *Relation du voyage à la recherche de la Pérouse*, with his thanks for having secured the return of his collections (Dawson 1958).

Labillardière's preparation of his collections for publication, and the publication of *Novae Hollandiae plantarum specimen* is dealt with in some detail by Stafleu (1967) who noted that

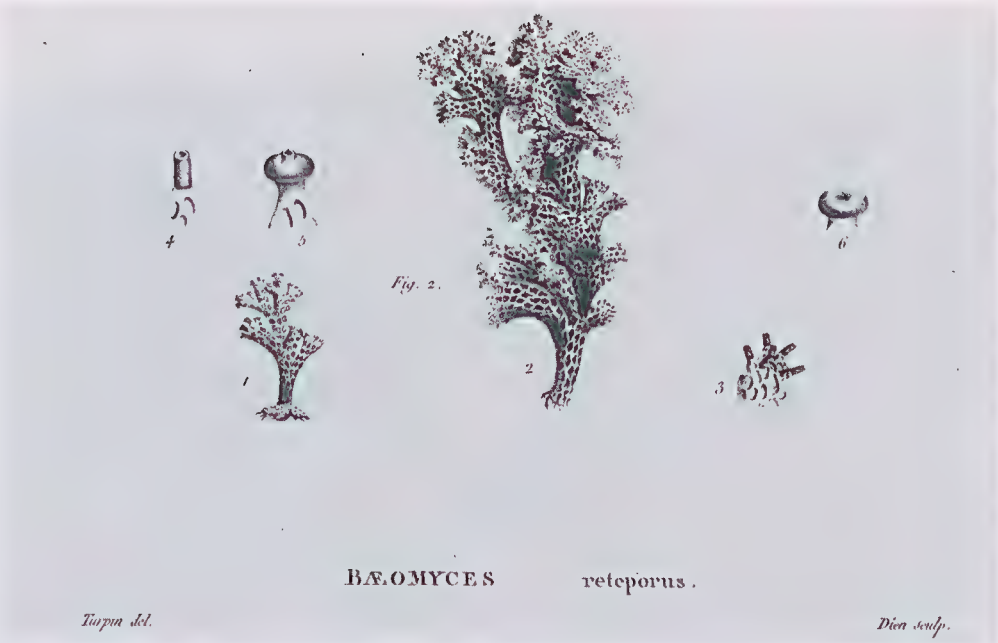

PLATE 3
Turpin's drawings of Baeomyces reteporus *from Labillardière's* Novae Hollandiae plantarum specimen.

Labillardière "never really worked up all his collections" being more of a "'botanist-voyageur' with the emphasis on 'voyageur'". Be that as it may, Labillardière did leave us the first formal description of an Australian lichen, and this singularly beautiful lichen is perfectly caught by Pierre Jean Francois Turpin's illustration in the *Specimen* (plate 3). Blunt (1950) described Turpin as "possibly the greatest natural genius of all the French botanical painters of his day". It is therefore fitting that a singular lichen should have a singular artist to first present its interest and beauty to the world. In 1834, Labillardière's plant collections were purchased by the wealthy English amateur botanist Philip Barker Webb (1793-1854). Webb lived for many years in Paris, where he was a close friend and colleague of Montagne, who determined much of his cryptogamic material including the Labillardière lichens, and during the last 14 years of his life often worked in Florence. Webb willed his enormous herbarium, his library and his house in Paris to the Grand Duke Leopoldo I of Tuscany in 1850, with the intention that the collections be added to the Erbario Centrale Italico, now the Herbarium Universitatis Florentinae (FI) of the University of Florence. The Webb Herbarium (FI–W) contains almost all of the holotypes of species Labillardière described from the Lebanon, Australia and New Caledonia. The holotypes are nearly always accompanied by the holograph description, in the exact text as published (Steinberg 1977). The holotype of *Baeomyces reteporus* has such an holograph description (plates 4 and 5), with isotype material also known in the British Museum of Natural History (BM) and the Museum National d'Histoire Naturelle, Laboratoire de Cryptogamie (PC) (see Wetmore 1963, Stafleu & Cowan 1979, Filson 1981). Labillardière's long-forgotten remaining Tasmanian lichens are detailed below for the first time since their discovery.

METHODS AND MATERIALS

Labillardière's Tasmanian lichens in FI-W (nomenclature follows Holmgren *et al.* 1981) are attached to paper sheets (46x27 cm) which have in the bottom left-hand corner a printed label (9.5 x 6.5 cm) stating "Herb. Webbianum. Ex Herb. Labillardière", with "Terra Diemen" added in most cases in ink (plate 6). Thin-layer chromatography

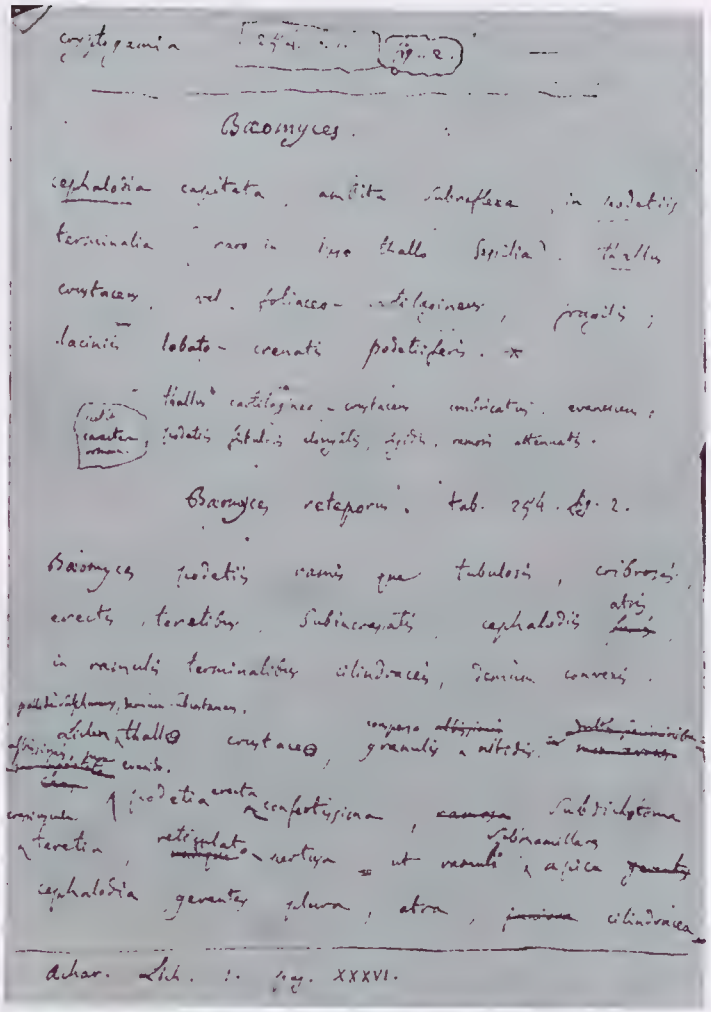

PLATE 4 *Labillardière's autograph description of* Baeomyces reteporus; *recto (FI–W).*

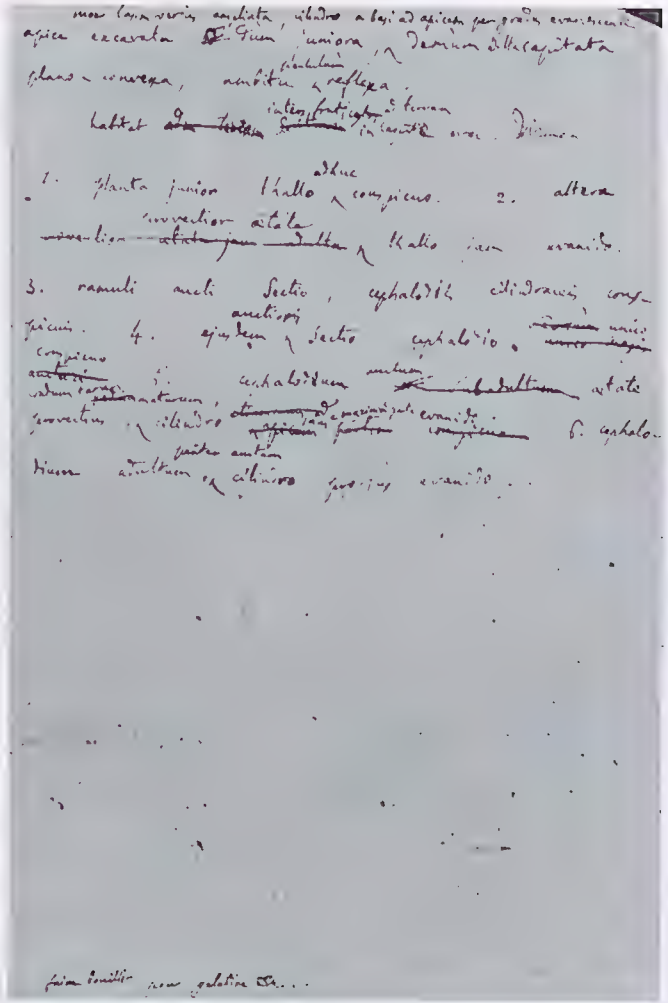

PLATE 5 *Labillardière's autograph description of* Baeomyces reteporus; *verso (FI–W).*

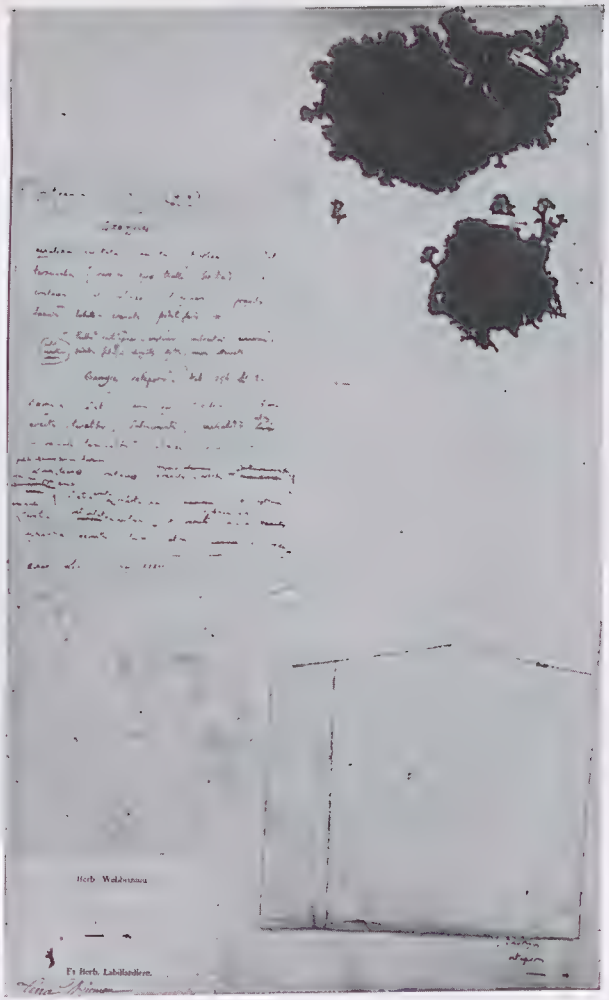

PLATE 6 *Holotype of* Baeomyces reteporus *Labill. (FI–W).*

PLATE 7 *Isolectotype of* Sticta billardierei *Delise (FI–W).*

(TLC) of acetone extracts of specimens was carried out using standardised methods (White & James 1985).

THE SPECIES

(1) *Baeomyces heteromorphus* Nyl. ex Church. Bab. & Mitten

Two packets are pinned to a sheet which is labelled by Montagne "*Biatora byssoidea* Fr.". The first packet contains *B. heteromorphus* overgrowing bryophytes, while the second contains small pieces of clay, much abraded, to which the lichen is attached. The species is discussed in Galloway (1980).

(2) *Cladia aggregata* (Swartz) Nyl.

One sheet, labelled by Montagne "*Cladonia aggregata* Spr.", has 21 specimens of a robust form of this lichen glued to two pieces of paper, 18 on the upper piece, 3 on the lower. On another sheet, material of *Cladia aggregata* (annotated by Montagne as "*Cladonia aggregata* Eschw.") occurs with specimens of *Sphaerophorus tener*. Another specimen of *C. aggregata* from Fée's herbarium (Flore de la Nouvelle Hollande) is annotated in Fée's hand "*Cladonia australia* Fée récolté par La Billardière" to which Montagne has added "Compre da Fée in Maggio 1854". The species is discussed in Filson (1981).

(3) *Cladia retipora* (Labill.) Nyl.

Material of this taxon is distributed on two herbarium sheets. What is designated here as the holotype of *Baeomyces reteporus* Labill. (plate 6) has two specimens (11x8 cm and 6x6 cm) pinned to the sheet on the top right-hand corner, and a paper packet containing several additional pressed specimens on the lower right-hand corner of the sheet. A small paper label marked "Baeomyces reteporus" in Labillardière's hand is pinned below this packet. Accompanying the lichen specimens is a single loose octavo sheet of paper written in ink on both sides in Labillardière's hand. The recto (plate 4) has a description of *Baeomyces* and part of the description of the new species *Baeomyces reteporus*, while the verso (plate 5) has the remainder of the species description as well as legends for the figure illustrating the species in *Novae Hollandiae Plantarum Specimen Vol.II* (plate 3).

Filson (1981: 23 and fig. 16b) designated material in Paris (PC) as lectotype without having seen the Labillardière herbarium in FI-W. Later, he designated the FI-W collections and additional PC material as isolectotypes (Filson 1986: 24–5). However, the presence of rich typical material together with Labillardière's holograph description amply qualify the FI-W material as holotype of *Baeomyces reteporus* (Art. 8.1). The PC material should therefore now be considered as isotype.

Additional isotype material exists on another sheet in FI-W and comprises a small specimen in a paper packet having an attached label in Labillardière's hand "*Baeomyces reteporus* Labill., n.holl. pl.Spec. t. 255. f.2". Further isotype specimens exist in BM (one labelled "*baeomyces reteporus* nh. pl.Spec. tab. 254" in Labillardière's hand, and another labelled "Dr Smith from M.Labillardière. New Holland", and one in LINN-SM 1710.17 (labelled in Smith's hand "New Holland. M.La Billardière, 1807. *Baeomyces reteporus* Bill. Specn. t. 254. f.2").

Writing of *Cladia retipora* (as *Cenomyce retipora*), W.J. Hooker stated "Nothing in nature can exceed the elegant lace-like appearance of this plant, a structure one would little expect to meet with in the humblest and least perfect part, as it is usually considered, of the vegetable creation, the Lichens. Labillardière, and following him, Acharius, ascribe a thallus to this species ... but my copious specimens exhibit no appearance of a thallus. If it exists, it is probably very evanescent ... The texture of the entire plant is, as it were, between crustaceous and cartilaginous, not much unlike that of our well-known *Cenomyce rangiferina*; but, instead of forming an uniform tubular membrane, the whole surface is a tissue of elegant network, the areolae oval or rounded, varying somewhat in size, but gradually becoming smaller in the ultimate small ramuli; then the inside, instead of being tubular, is filled with the same tissue of network anastomosing in every direction from the base to the summit of all the branches ..." (Hooker 1842).

(4) *Cladonia scabriuscula* (Delise) Leighton

Material (a small collection of 3–4 podetia) referable to this species is pinned to a sheet, and is annotated "*Cladonia furcata* Hoffm." in Montagne's hand. A small packet pinned to the base of the same sheet contains *Stereocaulon ramulosum* and has an associated label. "*Stereocaulon Cenomyce furcata* var. *monstrosa*" in Philip Barker Webb's hand.

PLATE 8
Labillardière's collection of Ramalina inflata *(J.D. Hook. & Taylor) J.D. Hook. & Taylor, annotated* "Ramalina physithalla" *by Montagne (FI-W).*

PLATE 9
Labillardière's collection of Sphaerophorus ramulifer *Lamb, annotated* "Sphaerophoron anceps" *by Montagne (FI-W).*

(5) *Cladonia southlandica* W. Martin

Eight specimens of this characteristic species are glued to a sheet which is annotated in Montagne's hand "*Cladonia australasica* Montag." with a previous epithet "Billardieri" crossed out. Neither of these herbarium names were subsequently used by Montagne. The species is discussed by Martin (1962), Ahti (1973) and Galloway (1985a).

(6) *Hypogymnia turgidula* (Bitter) Elix

Eight specimens attached to small twigs are pinned to a sheet. The species is discussed by Elix (1979). The sheet also contains a specimen of a fertile, non-sorediate *Menegazzia*, referable to *M. weindorferi*, and a small specimen of *M. caesiopruinosa*.

(7) *Leptogium azureum* (Swartz) Mont.

Two specimens are glued to a sheet labelled "*Collema azureum* Ach.". The species is discussed by Jørgensen & James (1983) and Galloway (1985a).

(8 *Menegazzia caesiopruinosa* P. James

This species is described and discussed in Kantvilas & James (1987: 25). See above under *Hypogemnia turgidula*.

(9) *Menegazzia weindorferi* (Zahlbr.) R. Sant.

This species is common in open forest habitats in Tasmania (Kantvilas *et al.* 1985, Kantvilas & James 1987). See above under *Hypogymnia turgidula*.

(10) *Parmelina stevensiana* Elix & Johnston

See below under *Ramalina inflata*. The species is described and discussed by Elix & Johnston (1986).

(11) *Parmelia tenuirima* J.D. Hook. & Taylor

See below under *Sphaerophorus tener*. The species is discussed by Galloway & Elix (1983), Galloway (1985a) and Hale (1987).

(12) *Pseudocyphellaria billardierei* (Delise) Räsänen

Three specimens (18x12 cm, 13x9 cm, 7x 3 cm) are pinned to a sheet which is annotated by Philip Barker Webb "voisin du *Sticta* Damaecornu Ach. *Sticta billardieri*" (plate 7). The material is without doubt of the same provenance as the lectotype specimen from Delise's herbarium in PC-LENORMAND (Galloway 1985a, 1988, Galloway & James 1986, Galloway *et al.* 1983), but is larger and in slightly better condition. The FI-W material is therefore isolectotype (Galloway 1988: 75).

(13) *Pseudocyphellaria multifida* (Nyl.) D. Galloway & P. James

Five small specimens are pinned to a sheet (their sizes range from 9x8 cm to 4x3 cm), one of them being attached to a small twig. Montagne has labelled the collection *Sticta Labillardierii* Delise" and another hand has written "*Sticta rigidula* Delise" (the latter annotation is possibly by Delise). However, the material is neither of these species, but typical *Pseudocyphellaria multifida*, a common Tasmanian forest epiphyte (Kantvilas & James 1987, Galloway 1988). A specimen of this material also exists in PC-MONTAGNE (Galloway *et al.* 1983: 141). This species was formerly recorded as *Pseudocyphellaria subvariabilis* (Galloway *et al.* 1983, Galloway 1985a, Kantvilas *et al.* 1985, Kantvilas & James 1987).

(14) *Ramalina inflata* (J.D. Hook. & Taylor) J.D. Hook. & Taylor

Nineteen specimens are glued to one sheet, two of them being attached to bark, the remainder free. The larger piece of bark has a small specimen of *Parmelina stevensiana* also attached. The sheet is annotated in Montagne's hand "*Ramalina physithalla* Montag." (plate 8), an unpublished herbarium name. Another sheet has five specimens of *Ramalina inflata* attached to small twigs, while an additional sheet has two pieces of bark containing *Ramalina inflata* and *Parmelina stevensiana*. *Ramalina inflata* is discussed by Stevens (1987).

(15) *Sphaerophorus ramulifer* Lamb

A sheet labelled "*Sphaerophoron anceps* Montag." (plate 9) in Montagne's hand (an unpublished herbarium name) has 18 specimens of *Sphaerophorus ramulifer* glued to it and two packets pinned separately. This species is commonly represented in open rainforest in Tasmania (Kantvilas *et al.* 1985), and is discussed by Tibell (1987).

(16) *Sphaerophorus tener* Laurer

Three specimens are attached to a sheet which also includes scraps of *Parmelia tenuirima*. The sheet has a small annotation label on the right-hand lower edge marked "*Sphaerophoron fragile* affinis" in pencil. The species is discussed by Tibell (1987).

(17) *Stereocaulon ramulosum* (Swartz) Räuschel

See above under *Cladonia scabriuscula*.

(18) *Usnea* cf. *angulata* Ach.

A large specimen (33 cm) containing protocetraric and usnic acids plus three unidentified compounds, is labelled "*Usnea longissima* Ach." in Montagne's hand.

(19) *Usnea molliuscula* Stirton

Ten small specimens of this species are glued to a sheet containing specimens of *Usnea oncodes* and *U. scabrida*, and labelled by Montagne as "*Usnea leucocarpa* Delise". One example is attached to a sheet containing *Usnea oncodes* and *U. scabrida*, labelled "*Usnea strigosa* Pers." by Montagne.

(20) *Usnea oncodes* Stirton

Five specimens of this characteristic sorediate species, together with five specimens of *Usnea scabrida* and ten specimens of *U. molliuscula*, are glued to a sheet labelled by Montagne "*Usnea leucocarpa* Delise". A further specimen is attached to a sheet labelled "*Usnea strigosa* Pers." by Montagne.

(21) *Usnea scabrida* Taylor

Five specimens are present on a sheet annotated by Montagne "*Usnea strigosa* Pers.", and five are present on a sheet labelled "*Usnea leucocarpa* Delise" by Montagne. All three species of *Usnea* mentioned above contain salazinic and usnic acids.

ADDITIONAL NOTES

(1) *Hypogymnia billardierei* (Mont.) Filson

Material labelled "*Parmelia billardieri* Fée, sur les Casuarinas récolté par LaBillardière" in Fée's hand is possibly type material of *Cetraria billardierei* Mont. [= *Hypogymnia billardieri* (Mont.) Filson]. The specimen is glued to a card which has Montagne's annotation "Compr da Fée in Maggio 1854". Fée's printed label is headed "Herbier de Fee. Flore de la Nouvelle Hollande". *Hypogymnia billardierei* is discussed by Elix (1979) who stated that it is widespread on bark, twigs of trees and dead wood in dry sclerophyll forests of New South Wales, Victoria and Tasmania, but is rather rare in South Australia. It is not certain whether this material from Fée's herbarium is from Tasmania or from the mainland of Australia, or whether in fact it is a genuine Labillardière collection.

(2) *Pseudocyphellaria neglecta* (Müll. Arg.) H. Magnusson

Material from Fée's herbarium (Flore de la Nouvelle Hollande) is annotated by Fée "*Sticta australis* Fée, sur les Casuarinas. Récolté par LaBillardière", to which Montagne has added "Compr. da Fée in Maggio 1854". Again, it is not certain whether this is a Tasmanian or mainland Australian collection, and doubt as to its provenance must be entertained until further Fée material is seen. This material, ascribed by Fée to Labillardière, may prove to be part of a later collection made by botanists on the expedition commanded by Nicolas Baudin (e.g. Leschenault de la Tour) which has in the past been confused with material collection by Labillardière (Nelson 1974, 1975, Carr & Carr 1976, Galloway & James 1986).

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REFERENCES

AHTI, T., 1973: Taxonomic notes on some species of *Cladonia* subsect. Unciales. *Annls bot. fenn.* 10: 163–184.

BLUNT, W., 1950: *THE ART OF BOTANICAL ILLUSTRATION*. Collins, London.

CARR, S.G.M. & CARR, D.J., 1976: The French contribution to the discovery of Australia and its flora. *Endeavour* 35: 21–26.

CARR, S.G.M. & CARR, D.J., 1981: A charmed life. The collections of Labillardiere. *In* Carr, D.J. &

Carr, S.G.M. (Eds): *PEOPLE AND PLANTS IN AUSTRALIA*. Academic Press, London: 79–115.

CHEVALIER, A., 1953: Un grand voyageur naturaliste normand J.-J. La Billardière (1755–1834). *Rév. Int. Bot. Appl. Agr. Trop.* 33: 97–124, 185–202.

DAWSON, W.R., 1958: *THE BANKS LETTERS*. British Museum (Natural History), London.

DE BEER, G.R., 1952: The relations between Fellows of the Royal Society and French men of science when France and Britain were at war. *Notes Rec. R. Soc.* 9: 244–299.

DE BEER, G.R., 1960: *THE SCIENCES WERE NEVER AT WAR*. Thomas Nelson, London: 45–68.

DUCKER, S.C., 1979: History of Australian phycology: the significance of early French exploration. *Brunonia* 2: 19–42.

ELIX, J.A., 1979: A taxonomic revision of the lichen genus *Hypogymnia* in Australia. *Brunonia* 2: 175–245.

ELIX, J.A. & JOHNSTON, J., 1986: New species of *Parmelina* (lichenised Ascomycotina) from Australia and New Zealand. *Brunonia* 9: 155–161.

FILSON, R.B., 1976: Australian lichenology: a brief history. *Muelleria* 3: 1830190.

FILSON, R.B., 1981: A revision of the lichen genus *Cladia* Nyl. *J. Hattori Bot. Lab.* 49: 1–75.l

FILSON, R.B., 1986: *INDEX TO TYPE SPECIMENS OF AUSTRALIAN LICHENS: 1800–1984. Austr. Faun. Fl. Ser.* 4. Canberra.

GALLOWAY, D.J., 1980: Notes on the lichen genus *Baeomyces* in New Zealand. *Bot. Notiser* 133: 77–83.

GALLOWAY, D.J., 1985a: *FLORA OF NEW ZEALAND LICHENS*. New Zealand Government Printer, Wellington.

GALLOWAY, D.J., 1985b: Lichenology in the South Pacific, 1790–1840. *In* Wheeler, A. & Price, J.H. (Eds): *FROM LINNAEUS TO DARWIN: COMMENTARIES ON THE HISTORY OF BIOLOGY AND GEOLOGY. Soc. Hist. nat. Hist. Special Vol.* 3: 205–214.

GALLOWAY, D.J., 1988: Studies in *Pseudocyphellaria* (lichens) I. The New Zealand species. *Bull. Br. Mus. nat. Hist. (Bot.)* 17: 1–267.

GALLOWAY, D.J. & ELIX, J.A., 1983: The lichen genera *Parmelia* Ach., and *Punctelia* Krog, in Australasia. *N.Z. J. Bot.* 21: 397–420.

GALLOWAY, D.J. & JAMES, P.W., 1986: Species of *Pseudocyphellaria* Vainio (Lichenes), recorded in Delise's "Histoire des Lichens: Genre *Sticta*". *Nova Hedwigia* 42: 423–490.

GALLOWAY, D.J., JAMES, P.W. & WILKINS, A.L., 1983: Further nomenclatural and chemical notes on *Pseudocyphellaria* in New Zealand. *Lichenologist* 15: 135–145.

GIBLIN, R.W., 1928: *THE EARLY HISTORY OF TASMANIA. THE GEOGRAPHICAL ERA 1642–1804*. Methuen, London: 102–136.

HALE, M.E., 1987: A monograph of the lichen genus *Parmelia* Acharius *sensu stricto* (Ascomycotina: Parmeliaceae). *Smiths Contr. Bot.* 66: 1–55.

HOLMGREN, P.K., KEUKEN, W. & SCHOFIELD, E.K., 1981: *INDEX HERBARIORUM*. Seventh edition. Bohn, Scheltema & Holkema, Utrecht.

HOOKER, W.J., 1842: On *Cenomyce retipora*. *Hook. Lond. J. Bot.* 1: 292–294.

JØRGENSEN, P.M. & JAMES, P.W., 1983: Studies on some *Leptogium* species of western Europe. *Lichenologist* 15: 109–125.

KANTVILAS, G., 1983: A brief history of lichenology in Tasmania. *Pap. Proc. R. Soc. Tasm.* 117: 41–51.

KANTVILAS, G. & JAMES, P.W., 1987: The macrolichens of Tasmanian rainforest: key and notes. *Lichenologist* 19: 1–28.

KANTVILAS, G., JAMES, P.W. & JARMAN, S.J., 1985: Macrolichens in Tasmanian rainforests. *Lichenologist* 17: 67–83.

LABILLARDIÈRE, M. [J.-J.H.] de, 1800: *VOYAGE IN SEARCH OF LA PÉROUSE. PERFORMED BY ORDER OF THE CONSTITUENT ASSEMBLY, DURING THE YEARS 1791, 1792, 1793, AND 1794*. Two volumes. John Stockdale, London.

LABILLARDIÈRE, J.-J.H. de, 1804–1806 [1807]: *NOVAE HOLLANDIAE PLANTARUM SPECIMEN*. Two vols. Dominae Huzard, Paris.

MARTIN, W., 1962: Notes on some New Zealand species of *Cladonia* with descriptions of two new species and one new form. *Trans. R. Soc. N.Z. (Bot.)* 2: 39–44.

NELSON, E.C., 1974: The locations of collection and collectors of specimens described by Labillardière in "Novae Hollandiae Plantarum Specimen" — additional notes. *Pap. Proc. R. Soc. Tasm.* 108: 159–170.

NELSON, E.C., 1975: The collectors and type locations of some of Labillardière's "Terra Van-Leuwin" (Western Australia) specimens. *Taxon* 24: 319–336.

STAFLEU, F.A., 1967: *ADANSON, LABILLARDIÈRE, DE CANDOLLE. INTRODUCTIONS TO FOUR OF THEIR BOOKS REPRINTED IN THE SERIES HISTORIAE NATURALIS CLASSICA*. J. Cramer, Lehre.

STAFLEU, F.A. & COWAN, R.S., 1979: *TAXONOMIC LITERATURE*. Volume II, H-LE. Bohn, Scheltema & Holkema, Utrecht.

STEINBERG, C.H., 1977: The collectors and collections in the Herbarium Webb. *Webbia* 32: 1–49.

STEVENS, G.N., 1987: The lichen genus *Ramalina* in Australia. *Bull. Br. Mus. nat. Hist. (Bot.)* 16: 107–223.

TIBELL, L., 1987: Australasian Caliciales. *Symb. Bot. Upsal.* 27: 1–279.

WETMORE, C.M., 1963: Catalogue of the lichens of Tasmania. *Rev. Bryol. Lichénol.* 32: 223–264.

WHITE, F.J. & JAMES, P.W., 1985: A new guide to microchemical techniques for the identification of lichen substances. *Bull. Br. Lich. Soc.* 57 (suppl.): 1–41.

(accepted 13 May 1988)

SOIL EROSION BETWEEN BIRCHS INLET AND ELLIOTT BAY, SOUTHWESTERN TASMANIA

by M. Pemberton

(with two tables, one text-figure and one plate)

PEMBERTON, M., 1987 (31:x): Soil erosion between Birchs Inlet and Elliott Bay, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 109–114. ISSN 0080–4703. Chemistry and Soils Section, Department of Agriculture, Hobart, Tasmania.

Organic soils (peats) in areas of southwestern Tasmania have been degraded by fire and subsequent erosive processes. An area affected by frequent firing has been examined and mapped to demonstrate the extent and severity of erosion. A high fire frequency is likely to lead to increased peat loss, a decrease in height and cover of vegetation and ultimately to areas denuded of peat. Implications for land management are discussed.
Key Words: soil erosion, organic soil, peat, southwestern Tasmania, soil erosion mapping, land degradation.

INTRODUCTION

Extensive areas of southwestern Tasmania are covered by blanket bogs that are particularly vulnerable to degradation by burning. Gore (1983) describes blanket bogs as organic soils or peats that are not confined to depressions but cover undulating terrain in response to a very humid climate. This paper examines the extent, severity type and topography location of erosion in an area south of Birchs Inlet. The literature contains no detailed accounts of soil erosion in southwestern Tasmania although nutrient loss following peat combustion has been recorded (Bowman 1980, Bowman *et al.* 1986, Brown & Podger 1982). Bowman & Jackson (1981) have commented on peat destruction, leaching of ash and overall decrease in nutrient levels following a prescribed burn of sedgeland/heath in this region. Wein (1981) has documented peat loss associated with burns in northwestern Tasmania and Kirkpatrick & Dickinson (1984) examined loss of surface soil organic matter after fire in Tasmanian alpine areas.

THE STUDY AREA

The study area is situated south of Macquarie Harbour and extends from Elliott Bay in the south to Birchs Inlet in the north, covering an area of 550 km^2 (fig. 1). Interbedded Tertiary gravels, sands, silts, clays and lignite bands occur across the northern extent of the area (i.e. north of Moores Valley airstrip) while Ordovician siliceous sediments are restricted to the area between Mount Osmund and the Wanderer River. East and south of Mount Osmund acid to intermediate rocks of the Cambrian Mount Read Volcanics occur while Cambrian granites are restricted to the area around Elliott Bay. The topography, which forms part of the lower coastal surface defined by Davies (1959), covers an altitudinal range of 0 to 400 m. Swampy conditions prevail around most water courses and the rest of the area is dominated by undulating plains or low, terraced slopes and plateaux.

Organic soil covers most of this terrain. Alluvial deposits are restricted to water courses and sands are associated with dunes around Elliott Bay. Organic soils have fibrous surface horizons which are usually 5 to 15 cm deep and reddish brown in colour, with underlying muck peat horizons that are between 10 and 20 cm deep and brown to grey in colour. The muck peats often grade into sandy gravels at approximately 30 cm. North of Moores Valley unconsolidated gravels, sands, silts or clays of Tertiary age may underlie the organic soils. In very poorly drained situations peats may reach 150 cm in depth.

Sedgeland/heath covers most of the study area with *Gymnoschoenus sphaerocephalus*, *Melaleuca squamea*, *M. squarrosa*, *Leptospermum nitidum*, *Restio* spp. and *Sprengelia incarnata* common, while scattered taller individuals of *Hakea epiglottis* and *Banksia marginata* often occur. Scrub has developed in some gullies with riverine rainforest along larger rivers (Davies 1983, Gibson 1986). Average annual precipitation in the study area varies between 1800 and 2000 mm.

Two bands of Aborigines, one from Port Davey, the other from Low Rocky Point frequented

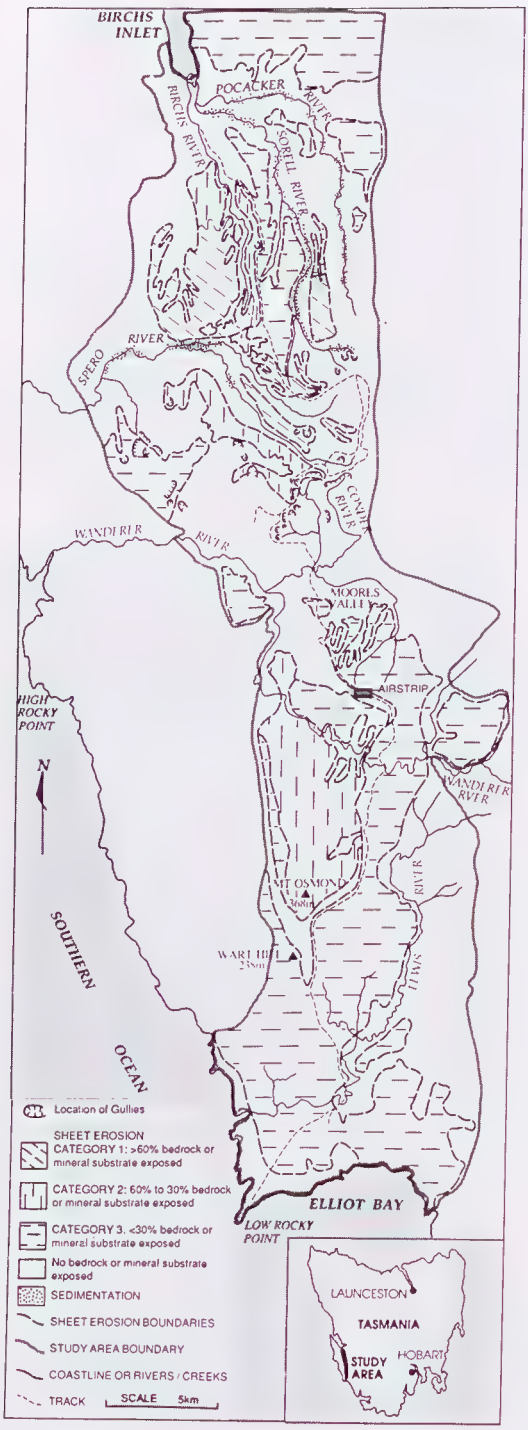

FIG. 1 — Extent and severity of various forms of soil erosion between Birchs Inlet and Elliott Bay, southwestern Tasmania.

the area between Elliott Bay and Birchs Inlet and kept it open by firing (Jones 1974). Most of these people were removed from the area in the 1830's. In the following years various explorers, surveyors, whalers and piners visited the region and commented on the open nature of the country (Gowlland & Gowlland 1975). It is likely that occasional firing occurred over the next one hundred years. Most of the recent fires have been attributed to fishermen, Commonwealth and Tasmanian Government employees and people involved with mineral exploration. For an indication of the location and approximate area affected by recent fires in the study area see table 1.

The study area, part of the South West Conservation Area, is managed by the Tasmanian Department of Lands, Parks and Wildlife. Mineral exploration is occurring in the region due to interest in the massive sulphide deposits associated with the Mount Read Volcanics (Large *et al.* 1987).

METHODS

To assess soil degradation, the study area was initially examined using aerial photographs (1:40 000 black and white photographs, flown 1984). Field inspection was conducted as part of the South West Land Systems Survey (Pemberton, in press). During this survey, information was collected on soils, soil erosion, vegetation (using TASFORHAB — see Peters 1984) and general site characteristics (e.g. topographic position, slope and drainage).

Aerial photographs and 1:100 000 topographic map sheets were used for detailed mapping of erosion types, as outlined in table 2. Estimates of percentage bedrock or mineral substrate exposure was made for each square kilometre to produce figure 1.

Sedimentation of creeks and rivers often occurs in the vicinity of sheet or gully eroded areas. Areas of sedimentation are shown in figure 1.

RESULTS

The extent of the various forms of erosion and sedimentation are shown in figure 1, and the extent of sheet erosion is presented in table 2. Sheet erosion has affected just over 42% (235 km^2) of the study area. Ground checks have confirmed the existence of sheet erosion over extensive areas where peat has not been completely removed. It appears that much of the study area, with the

TABLE 1
Recent Fires in the Study Area*

Date	Location	Approx. area burnt (km²)
1969–70	North from Low Rocky point	20
1973–74	South from Birchs Inlet to Moores Valley	90
1975	Northeast region	55
1976	Western edge	25
1977–78	Southwestern edge	10
1985	Birchs Inlet to Elliott Bay	335

* From unpubl. map, Department of Lands, Parks and Wildlife.

exception of some swamp and coastal environments, has been seriously degraded by this form of erosion. Conservative estimates suggest that at least 50 km² is almost devoid of soil.

The most severe degradation has occurred between Birchs Inlet and the Wanderer River, where peat horizons overlie Tertiary deposits. These peat horizons have been removed by wind, water and fire from well drained slopes, ridges and crests. They are more susceptible to degradation than organic soil of adjoining lowland swamps because they are more exposed and tend to dry out more rapidly. Sheet erosion has left most of the steeper country with a denuded appearance (plates 1C and 1D) and field observations suggest up to 0.3 m of peat have been lost from areas where bedrock is exposed.

Serious gully erosion appears to be restricted to the area between the Conder and Spero Rivers and to a small region north of the Spero River. The gullies typically occur at the headwaters of drainage lines and often coalesce to form larger units which can be over 10 m deep and 50 m wide with gently inclined floors but precipitous walls.

Large volumes of material from gully and sheet erosion have probably contributed to an increased rate of sedimentation on alluvial flats along sections of the Birchs, Sorell, Spero and Pocacker Rivers where decreased stream gradients and velocities favour sediment deposition.

TABLE 2
Erosion Types, and Areas Affected by Sheet Erosion

Type	Description	Areas affected (km²)	Percentage of study area
Gully	Erosion that forms large gullies at headwaters of drainage lines (plates 1A and 1B)l		
Sheet	Removal of soil layers by fire, wind and water (plates 1C and 1D). Sheet-eroded areas were identified where bedrock or mineral substrate exposure was evident. Sheet erosion has been classified into:		
	Category 1 — >60% bedrock or mineral substrate exposed;	20	3.6
	Category 2 — 60–30% bedrock or mineral substrate exposed; and	45	8.2
	Category 3 — <30% bedrock or mineral substrate exposed.	170	31.0
		Total 235	42.8

A

B

C

D

PLATE 1

(A) Gullies forming at the headwaters of drainage lines after peat removal. (B) Small gullies coalesce to form larger units. Geology: unconsolidated Tertiary gravels, sands and clays. (C) Severe sheet erosion on well drained positions in the Moores Valley area. (D) Sheet erosion on crests, slopes and ridges near Moores Valley.

DISCUSSION

The study area includes some of the most severely eroded and degraded land in southwestern Tasmania. Although firing during aboriginal occupation may have initiated soil erosion it is likely that frequent firing in recent times has intensified this problem. Large tracts of land in the region with organic soils and sedgeland/heath vegetation have been affected by sheet erosion. This includes areas surrounding Point Vivian, the Ironbound Range, Ped Point Hills, the New Harbour Range, Rowitta Plains, Mount Rugby, Lost World Plateau, North Broken Hill and the Lawson Range, Giblin River Plains, Piners Peak and the Denison, De Witt, Erskine and Propsting Ranges. The sedgeland/heath vegetation associated with peat soils in Tasmania is prone to firing due to the flammability of many of the species (such as *Gymnoschoenus sphaerocephalus* and various *Melaleuca*, *Leptospermum*, *Baeckia* and *Boronia* spp.), and the hot, dry conditions, which are relatively common during summer.

Firing promotes sheet erosion be removing vegetation which binds the organic soil but more seriously by burning peat and producing an ash that is easily removed by wind and water. Frequent, strong westerly winds, and a high annual average rainfall intensify the problem. Sheet erosion can occur relatively rapidly on peats compared to mineral soils, with destruction of up to 0.2 m of organic soil in one prescribed burn (Bowman & Jackson 1981).

Peat absorbs water and reduces the rate of runoff. Therefore any substantial loss of this soil results in increased surface water flow. Reduced vegetation cover on areas of denuded peat intensifies this problem. Both of these factors contribute to the spread and development of sheet and gully erosion.

Gullies appear to have developed in some places after the removal of peat horizons by sheet erosion. The main occurrences are between the Spero and Wanderer Rivers (fig. 1). They have formed on Tertiary gravels, sands, silts and clays which are relatively unconsolidated and vulnerable to erosion. Erosion appears to be removing material from both the headwaters and sides of the gullies.

Large quantities of sediment, derived from gully and sheet eroded areas, is transported into creeks and rivers. This increases the potential for flooding as there is more material in the drainage lines and less peat in the catchments. An increase in organic matter in drainage lines could in some cases lead to eutrophication.

Organic soils are very important nutrient sources in the blanket bogs (Bowman & Jackson 1981) particularly as they often overlie infertile siliceous substrates. They can be degraded by firing, and some authors have suggested that, although fires have occurred in the region for thousands of years, frequencies have increased over recent times (Kirkpatrick 1983). Although some arise from lightning strikes (Hodge 1983) many result from acts of arson or are started by accident. Such fires are most likely to start during hot, dry summer conditions when peat burns are most likely. Hazard reduction burns have been carried out for the last couple of decades in the region and some have destroyed peat horizons. Organic soils near the Scotts Peak Road were destroyed by a hazard reduction burn (Bowman & Jackson 1981) while another in the Vale of the Rasselas extended up the slopes of the Denison Range with similar results. Tyson (1983) reported that a hazard reduction burn in the Port Davey area did little damage to root systems as the soil was saturated, which suggests there was little or no loss of peat.

The most recent fire in the study area escaped from a burn intended to create a favourable habitat for the rare orange-bellied parrot. Re-assessment of this kind of land management is needed in a region where it is impossible for the peat-forming process to keep pace with soil loss. It may take decades to restore organic soil cover in the absence of further disturbance. If the area is to be stabilised, attempts must be made to limit firing. If frequent firing continues, peat loss on well drained sites is inevitable, with an increase in gully erosion, sedimentation, and flooding. Some sheet-eroded areas have minor peat accumulations where peat redevelopment could occur. Frequent firing in southwestern Tasmania has consumed organic soil, initiated sheet erosion and reduced the nutrient level of peatlands.

The rate of peat formation has not been measured in the region but it is likely to be extremely slow. Horizons which probably took centuries to form can burn in a few hours. Considerable work on aspects of peat ecology, including the extent of peat erosion, rate of peat development, and the effects of prescribed burning on peat, is required if Tasmanian peats and dependent plants and animals are to be appropriately conserved.

ACKNOWLEDGEMENTS

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REFERENCES

BOWMAN, D.M.J.S., 1980: Fire, nutrient and vegetation interactions in South West Tasmania. Unpubl. Hons thesis, Univ. Tasm. Bot.

BOWMAN, D.M.J.S. & JACKSON, W.D., 1981: Vegetation succession in South West Tasmania. *Search* 12(10): 358–362.

BOWMAN, D.M.J.S., MACLEAN, A.R. & CROWDEN, R.K., 1986: Vegetation–soil relations in the lowlands of South West Tasmania. *Aust. J. Ecol.* 11: 141–153.

BROWN, M.J. & PODGER, F.D., 1982: Floristics and fire regimes of a vegetation sequence from sedgeland-heath to rainforest at Bathurst Harbour, Tasmania. *Aust. J. Bot.* 30: 659–676.

DAVIES, J.B., 1983: Huon pine survey 1983. *Tech. Rep.* 83/2. Tasm. Natl Pks Wildl. Serv.: 46 pp.

DAVIES, J.L., 1959: High level erosion surfaces and landscape development in Tasmania. *Aust. Geogr.* 7: 193–203.

GIBSON, N., 1986: Conservation and management of Huon pine in Tasmania. *Tech. Rep.* 86/3. Tasm. Natl Pks Wildl. Serv.: 91 pp.

GORE, A.J.P., 1983: *ECOSYSTEMS OF THE WORLD. 4A — MIRES: SWAMP, BOG, FEN AND MOOR*. Elsevier, Amsterdam: 350 pp.

GOWLLAND, R. & GOWLLAND, K., 1975: *TRAMPLED WILDERNESS — THE HISTORY OF SOUTH-WEST TASMANIA*. Richmond and Sons, Devonport: 160 pp.

HODGE, G., 1983: The practical aspects of fire control. *In* Gee, H. & Fenton, J. (Eds): *THE SOUTH WEST BOOK*. Australian Conservation Foundation, Collins: 308 pp.

JONES, R., 1974: Tasmanian tribes. *In* Tindale, N.B. (Ed.): *ABORIGINAL TRIBES OF AUSTRALIA*. ANU Press: appendix.

KIRKPATRICK, J.B., 1983: Fire and plant communities in the South West. *In* Gee, H. & Fenton, J. (Eds): *THE SOUTH WEST BOOK*. Australian Conservation Foundation, Collins: 308 pp.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984: The impact of fire on Tasmanian alpine vegetation and soils. *Aust. J. Bot.* 32: 613–629.

LARGE, R.R., HERRMAN, W. & CORBETT, K.D., 1987: Base metal exploration of the Mount Read Volcanics, western Tasmania: part 1. Geology and exploration, Elliott Bay. *Econ. Geol.* 82(2): 267–289.

PEMBERTON, M., in press: *LAND SYSTEMS OF TASMANIA. REGION 7 — THE SOUTH WEST*. Department of Agriculture, Tasmania.

PETERS, D.G., 1984: TASFORHAB. *In* Meyers, K. & Musto, I. (Eds): *PROCEEDINGS OF A WORKSHOP ON SURVEY METHODS FOR NATURE CONSERVATION*. CSIRO, Canberra: 179–192.

TYSON, R., 1983: Fire management in National Parks. *In* Gee, H. & Fenton, J. (Eds): *THE SOUTH WEST BOOK*. Australian Conservation Foundation, Collins: 308 pp.

WEIN, R.W., 1981: Characteristics and suppression of fires in organic terrain in Australia. *Aust. For.* 44(3): 162–169.

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EPACRIS CURTISIAE, A NEW SPECIES FROM NORTHWESTERN TASMANIA

by S.J. Jarman

(with two text-figures)

JARMAN, S.J., 1988 (31:x): *Epacris curtisiae*, a new species from northwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 122(2): 115–117. ISSN 0080–4703. Department of Lands, Parks & Wildlife, G.P.O. Box 44A, Hobart, Tasmania, Australia 7001.

A new species of *Epacris* is described. It is restricted to northwestern Tasmania where it is a prominent component of heathland vegetation on peaty soils.
Key Words: Epacridaceae, *Epacris*, Tasmania.

INTRODUCTION

Epacris is restricted to the eastern Australian mainland, Tasmania and New Zealand. It contains approximately 40 species, 21 of which have been reported previously from Tasmania (including 14 endemics). The genus is a common component of heathland vegetation and is widespread throughout the state. However, individual species may be very localised, as exemplified by *Epacris curtisiae* sp. nov. which is known only from a small area in northwestern Tasmania.

DESCRIPTION

Epacris curtisiae S.J. Jarman sp. nov.

Frutex ad 0.5–2 (-5) m altus caulibus uno ad plures erectis gracilibus; ramuli pubescentes; caules veteriores asperi cicitricibus foliorum prominentibus. Folia erecto-patentia; lamina plana vel parum concava, late obovata vel suborbicularis vel late ovata, 3–6 mm longa, 2.5–4.5 mm lata, crassa anguste hyalino-marginata, margine scaberulo, apice obtuso vel late acuto, supra glabra praeter pilos breves in triangulo parvo basi dispositos, subtus glabra, 3–5 nervis, distaliter parum carinata, apice incurvo; petiolus brevis, 0.5–1 mm longus, supra puberulus subtus glaber. Flores solitarii conferti, in capitula foliata brevia 1–5 cm longa in extremitatibus ramulorum aggregati; pedicelli 1–1.5 mm longi. Bracteae 9–12, 1–3.5 mm longae, ovatae vel ovatae-ellipticae, ciliolatae; sepala ovata-elliptica, 3–4 mm longa, ciliolata saepe colore roseo suffuso, apice obtuso. Corolla alba; tubus cylindricus vel anguste infundibuliformis, 2.5–3.5 mm longus; lobi obtusi, 2.5–3 mm longi, tubo breviores vel fere aequantes. Stamina inclusa; antherae 0.8–1.2 mm longae, filamenta 0.2–0.35 mm longa. Discus e squamis 5 obtusis constatus. Stylus brevis, 0.6–1 mm longus, basim versus paulo tumidus; stigma antheras haud attingens.

Typus: Australia, Tasmania, Rebecca Road, 1 km west of Nelson Bay River in buttongrass (*Gymnoschoenus sphaerocephalus*) moorland, 150 m, 27.ix.1985, S.J. Jarman and G. Kantvilas 287. (Holotypus: HO 101085. Isotypi: AD, CANB, MEL, NSW)

Shrub from 0.5–2 (-5) m high, with one to several erect slender stems; branchlets pubescent, older stems rough with raised leaf scars. Leaves half-spreading; blade flat or slightly concave, broadly obovate to almost orbicular to broadly ovate, 3–6 mm long, 2.5–4.5 mm wide, thick, with a narrow hyaline scaberulous margin, apex blunt to broadly acute, upper surface glabrous except for short hairs forming a small triangle at the base, lower surface glabrous with 3–5 weak nerves, slightly keeled distally with the short callous tip incurved; petiole short, 0.5–1 mm long, puberulent on the upper surface, glabrous on the underside. Flowers solitary, crowded, forming short leafy heads 1–5 cm long at the ends of the branches; pedicels 1–1.5 mm long. Bracts 9–12, 1–3.5 mm long, ovate or ovate-elliptical, ciliolate; sepals ovate-elliptical, 3-4 mm long, ciliolate, often tinged with pink, apex blunt. Corolla white; tube cylindrical or narrowly funnel-shaped, 2.5–3.5 mm long; lobes blunt, 2.5–3 mm long, shorter than or almost equal to the tube. Stamens included; anthers

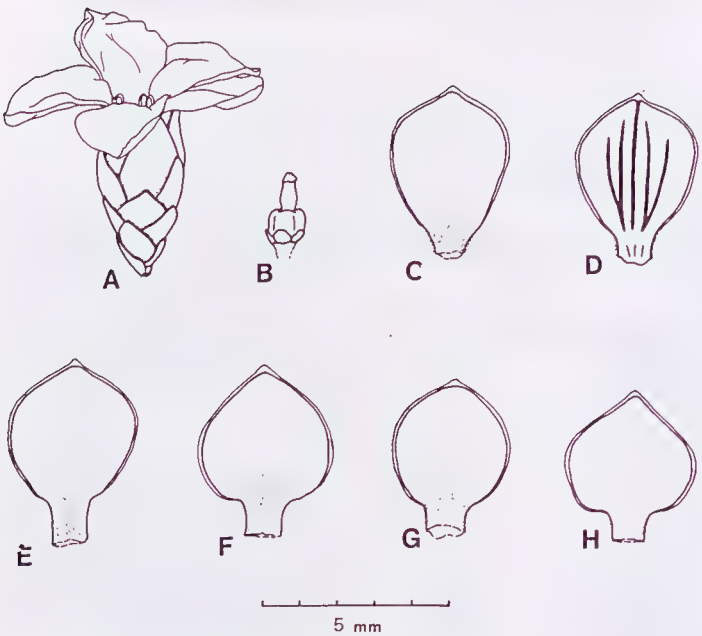

FIG. 1 — Epacris curtisiae: *(A) flower, (B) gynoecium, (C) upper leaf surface, (D) lower leaf surface, (E–H) variation in leaf shape.*

0.8–1.2 mm long, filaments 0.2–0.35 mm long, attached at the midpoint of the anther. Disk of 5 blunt scales. Style short, 0.6–1 mm long, slightly swollen towards the base; stigma below the anthers.

The above description of *E. curtisiae* was compiled from fresh material. As the plant dries, the leaves become more concave, the incurved apex is more accentuated and the venation becomes obscure. The plant is illustrated in figure 1.

The new species is named after Dr Winifred M. Curtis, in recognition of her contribution to knowledge of the Tasmanian flora.

Specimens Examined: Tasmania, Brooks Creek, near Ordnance Point, M. Cameron s.n., 26.iii.1981 (HO 39676). Rebecca Road, 1 km west of Nelson Bay River in buttongrass moorland, 150 m, S.J. Jarman & G. Kantvilas 288, 27.ix.1985 (HO, AD, MEL, NSW, BRI, CANB, CBG, PERTH, AK, CHR). Mt Bertha Road, in buttongrass moorland, 210 m, S.J. Jarman & G. Kantvilas 289, 27.ix.1985 (HO, AD, MEL, NSW). Rebecca Road, 1.5 km east of Nelson Bay River, 150 m, S.J. Jarman & G. Kantvilas *s.n.*, 3.iv.1984 (HO 82457). Blackwater Road, west of the Frankland River, S.J. Jarman & G. Kantvilas *s.n.*, 15.ix.1984 (HO 88590). Mt Balfour, A. Moscal 4937, 17.xii.1983 (HO). Dempster Lookout, A. Moscal 7567, 12.iv.1984 (HO).

DISCUSSION

Epacris curtisiae is distinct from any other species of the genus although it is not characterised by any single diagnostic feature. Its closest affinities are with *E. serpyllifolia* R. Br. It differs from this species in having a shorter style, obtuse to broadly acute sepal apices (acute in *E. serpyllifolia*) and anthers more hidden in the corolla tube. The two species overlap in leaf shape for part of their range (ovate to broadly ovate leaves) but obovate or broadly obovate leaves are common in populations of *E. curtisiae* whereas they do not occur in populations of *E. serpyllifolia*. Furthermore, in *E. curtisiae* sp. nov., the hyaline point at the leaf apex is blunter and shorter than that usually found in *E. serpyllifolia* populations, and is never sharp. On drying, the tip turns opaque and forms a short callous point which is distinctly incurved. In *E. serpyllifolia*, the leaf point is either straight or only slightly incurved, and the leaves are somewhat prickly. The two species are separated by their flowering times, with *E. curtisiae* flowering from August to October and *E. serpyllifolia* flowering from November to January.

Epacris curtisiae grows in peaty soils on undulating terrain where it is locally common in heathlands, graminoid heathlands and scrub. In young vegetation it is represented by slender plants

with one or two stems. This habit may be maintained with increasing age, particularly in scrub communities where plants up to c. 5 m tall may be present. More commonly, however, the plants become multistemmed from ground level and form robust bushy individuals 1–2 m high.

Epacris curtisiae is known only from northwestern Tasmania where it occurs at altitudes below about 300 m. It has been recorded from Dempster Plains, and from buttongrass moorland around Nelson bay River. In the latter area, it has been recorded as far south as Mt Balfour and extends from the coast to just east of the Frankland River on Blackwater Road. It was not found on Lawson and Neasey Plains to the northeast of Dempster Plains in spite of the similar vegetation occurring there. Its distribution is shown in figure 2, using a format consistent with that adopted by Brown *et al.* (1983) in their atlas of endemic Tasmanian plants.

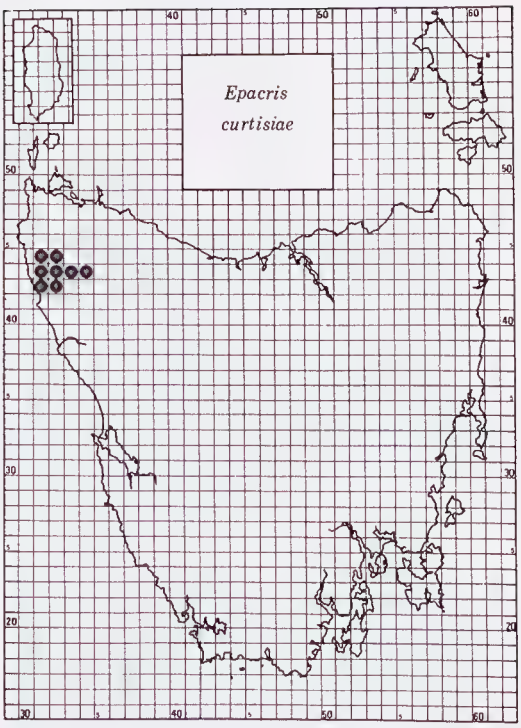

FIG. 2 — Distribution of Epacris curtisiae *on a 10 km grid.*

ACKNOWLEDGEMENTS

I wish to thank N.K. Robson (British Museum) and A.E. Orchard (Tasmanian Herbarium) for checking the Latin description, and M.J. Brown, R.K. Crowden, G. Kantvilas, A.E. Orchard and J.M. Powell for comments on the draft manuscript. Use of facilities at the Tasmanian Herbarium are also acknowledged with thanks. The work was undertaken during a project funded by the Tasmanian Forest Research Council, the State Fire Commission, the Forestry Commission and the Department of Lands, Parks & Wildlife.

REFERENCE

BROWN, M.J., KIRKPATRICK, J.B. & MOSCAL, A., 1983: *AN ATLAS OF TASMANIA'S ENDEMIC FLORA*. Tasmanian Conservation Trust, Hobart.

(accepted 21 October 1987)

A STUDY OF THE LIFE HISTORY OF *MICROPHALLUS PARAGRAPSI* SMITH 1983 (TREMATODA : MICROPHALLIDAE)

by P. J. Bell

(with three tables and four text-figures)

BELL, P. J., 1988 (31:x): A study of the life history of *Microphallus paragrapsi* Smith 1983 (Trematoda : Microphallidae). *Pap. Proc. R. Soc. Tasm.* 122(2): 119–125. ISSN 0080–4703. 43 Waterloo Crescent, Battery Point, Tasmania, Australia 7000; formerly Department of Zoology, University of Tasmania.

Metacercariae of the microphallid trematode *Microphallus paragrapsi* Smith 1983 were found in the nervous system of the smooth pebble crab *Philyra laevis* (Bell 1855). Sporocysts of *M. paragrapsi* were found in the hepatopancreas of the intertidal gastropod *Assiminea brazieri* (Tenison Woods 1876). Under laboratory conditions, cercariae were found to emerge from the snail host and invade the intertidal crab *P. laevis*, where they subsequently encysted within the nerves innervating the legs and claws. Adults of *M. paragrapsi* were found in the gut of the Pacific gull *Larus pacificus* (Latham 1801). The life history of *M. paragrapsi* is very similar to the life history of the related species *Microphallus pachygrapsi* Deblock & Prevot 1969.

Key Words: *Microphallus paragrapsi*, life-history, microphallid, crab, Tasmania.

INTRODUCTION

In 1982, during a study of parasites of the smooth pebble crab *Philyra laevis* (Bell 1855), metacercariae were found in the nervous system of crabs from a number of localities in Tasmania. On excystment *in vitro*, the metacercariae were identified as those of the microphallid *Microphallus paragrapsi* Smith 1983 which was first described from specimens found in the nervous system of another foreshore crab, *Paragrapsus gaimardii* (M. Edw.). Only one other microphallid, *Microphallus pachygrapsi* Deblock & Prevot 1969, has been recorded from the nervous system of its crustacean intermediate host.

Since there is a paucity of information on the biology of M. *paragrapsi* an investigation of the life history was undertaken and is the subject of this paper.

METHODS AND MATERIALS

Crabs *Philyra laevis* were collected from Great Bay and Barnes Bay, Bruny Island, and Pipe Clay Lagoon in southeastern Tasmania. They were maintained in the laboratory for up to one week prior to dissection and examination. A record was made of the degree and incidence of infection with cysts of *M. paragrapsi*.

Crabs collected from Barnes Bay were found to be suitable for experimental infection as the incidence of infection appeared to be very low. Of 200 crabs examined throughout the study period, none were infected by *M. paragrapsi* and only one crab was found to be infected with a single cyst of the trematode *Maritrema eroliae* Yamaguti 1939.

Metacercarial cysts were dissected free of host tissue, rinsed and stored at 5°C in Hank's Balanced Salt Solution (Hank's BSS) for up to one week prior to excystment procedures. The technique and solution sequences used for excystment followed those given by Smith (1983) for the excystment of *M. paragrapsi*.

Fourteen species of mollusc were collected from Great Bay at monthly intervals between March and September 1982, and nine species from Pipe Clay Lagoon at irregular intervals during the same year (table 1). Snails were maintained in the laboratory and monitored for release of cercariae. Those found to be releasing xiphidocercariae were maintained in isolation with crabs (considered to be free from infection) collected from Barnes Bay, Bruny Island. These crabs were subsequently dissected and examined for cysts of *M. paragrapsi*. By this process, the minute intertidal gastropod *Assiminea brazieri* (Tenison Woods 1876) was implicated as a primary host for *M. paragrapsi*.

Newly emerged cercariae were collected from vials containing *A. brazieri* in filtered sea water. This material was used for description of cercariae, experimental infection of crabs and observations on behaviour. Additional material was collected from freshly dissected snails. Crabs experimentally infected with cercariae were maintained at 30°C in filtered sea water until dissection.

Several species of birds were found to frequent Great Bay and Pipe Clay Lagoon, including the pied oyster catcher, silver gull and Pacific gull. In the summer of 1981/82 G. Coulson (pers. comm.) identified crabs *P. laevis* and *P. gaimardii*, from regurgitated pellets of the Pacific gull, on Green Island, in southeastern Tasmania. This evidence implicated the Pacific gull as a definitive host for *M. paragrapsi*. In October 1982, after obtaining a permit from the Tasmanian National Parks and Wildlife Service, two Pacific gulls (1 male, 1 female) were shot at Pipe Clay Lagoon. Dissection was carried out within a few hours of death. The oesophagus, crop, gizzard, liver and pancreas were removed and examined for the presence of adults of *M. paragrapsi*. The intestine (gizzard to anus) was cut into twelve equal lengths and each was examined separately for adult worms.

Examination of live material was facilitated by placing worms on a slide under slight coverslip pressure and when necessary, worms were immobilised by warming the slide. Aqueous vital stain solutions, brilliant cresyl blue and neutral red, were used to observe glands and ducts. All observations were made using a dissecting microscope and a Carl Zeiss compound microscope. The measurements of adult worms, metacercariae, excysted metacercariae, sporocysts and other larval worms are based on specimens fixed in 10% phosphate-buffered formol saline, under coverslip pressure. Measurements are given in microns, the mean first, followed by the range in brackets.

RESULTS

Life History

Sporocysts were found on the hepatopancreas of the gastropod *Assiminea brazieri*. As many as 100 sporocysts were dissected from the host tissue of a single snail. In October, one of 200 snails collected from Great Bay and eight of 100 snails collected from Pipe Clay Lagoon were found to be infected.

Under laboratory conditions, cercariae were observed to emerge from the snail host and continue swimming until exhausted or contacting the gill surface of the crab *Philyra laevis*. By the respiratory current, cercariae were drawn into the branchial chamber of the crab. On contact with the gill surface the tail was discarded and cercariae crawled between adjacent gill lamellae and penetrated the branchial vein.

Crabs, that had been experimentally exposed to cercariae and dissected after 30 minutes, had tailless cercariae between gill lamellae and post-cercariae within the branchial vein. After 18 hours (fig. 1B), several post-cercariae were found in the haemocoels. After 4 days (fig. 1C) immature cysts were present in the major nerves innervating the

TABLE 1
Molluscs Examined for Larval Trematodes

Species	Number of individuals examined	
	Great Bay	Pipe Clay Lagoon
Zeacumantus diemenensis	400	400
Parcanassa pauperata	1200	1800
Melarapha unifasciata	300	
M. praetermissa	40	
Austrocochlea constricta	300	200
A. concamerata	50	
Lepsiella vinosa	200	
Cominella lineolata	120	25
Salinator fragilis	200	400
Bembicium auratum	300	250
Assiminea brazieri	200	200
Anepella cycladaa	100	300
Katelysia scalarina		100
Mytilus planulatus	30	

legs. Cyst diameter measured about 250 µm. The cyst wall was extremely fine and single layered. The penetration glands and the oral sucker were indiscernible. The tegumental spines were prominent and the excretory bladder had increased in size. After 14 days (fig. 1D), cyst diameter measured about 295 µm. The cyst wall was two layered, the outer layer radially striated. The oral sucker was well developed, the ventral sucker was partially developed, though small in diameter, and the excretory vesicle was large and well developed.

Although metacercarial cysts usually were found in the major nerves innervating the legs and the claws of the crab P. laevis, cysts were found less frequently in the abdominal nerve or one of the major nerves leading to the cephalic appendages. Of 264 crabs (112 female, 152 male), collected from Great Bay between March and September, 233 were found to be infected with metacercarial cysts. The mean degree of infection was 11 (range 1–102) cysts per crab (all of ten crabs collected from Pipe Clay Lagoon were infected, with a mean of 53 cysts per crab). A peak of 18 cysts per crab (mean number of cysts per crab in a sample of 50 crabs) of *Philyra laevis* at Great Bay occurred in June. This corresponded with a peak in the incidence of infection (96%) and the highest mean percentage of immature cysts present per crab (43%).

Ovigerous adult worms *M. paragrapsi* were found in the posterior half of the intestine of the Pacific gull *Larus pacificus* (fig. 2). Both of the birds examined were found to be infected; one bird contained 550 adult worms of *M. paragrapsi*.

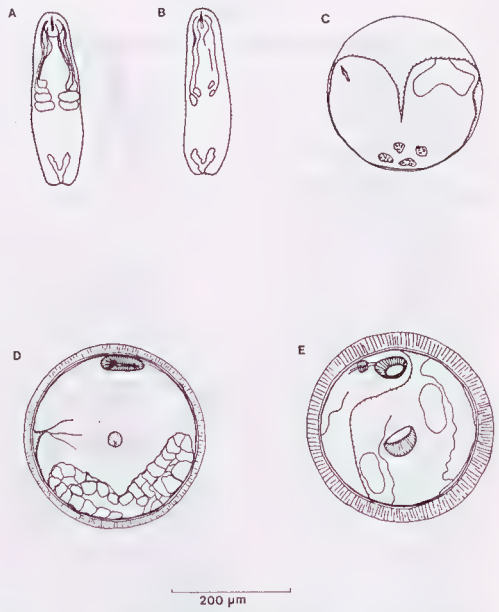

FIG. 1 — Microphallus paragrapsi. *Growth and development in the crab host* Philyra laevis. *(A) after 1 hour at room temperature; (B) after 18 hours at 30°C; (C) after 4 days at 30°C; (D) after 14 days at 30°C; (E) mature metacercarial cyst.*

Descriptions

Sporocyst (fig. 3C)

Mature sporocysts are elongate and contain up to about 8 cercariae; mean 5 (range 2–8). Small less mature sporocysts are oval in shape. Ten elongated fairly mature sporocysts measured 579 µm (350–850) by 193 µm (120–250).

Cercaria (figs 3A, 3B)

The cercaria is a small monostome xiphidiocercaria, characteristic of the family Microphallidae. The body and tail are highly contractile. Minute tegumental spines cover the body which measures 268 µm (260–288) by 65 µm (60–78). An aspinose tail joins the body at the

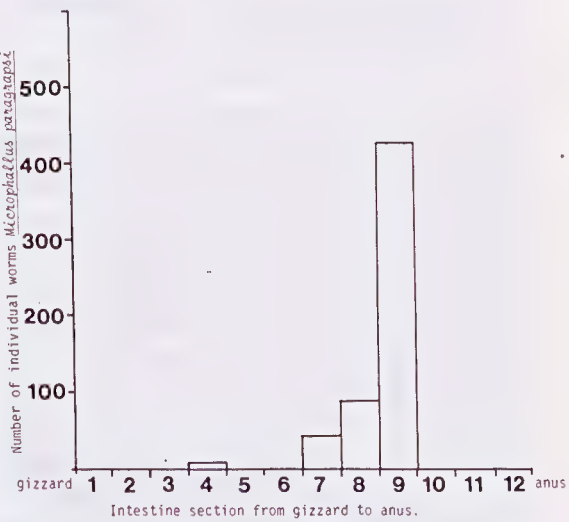

FIG. 2 — *Site of infection of* Microphallus paragrapsi *in the Pacific gull* Larus pacificus.

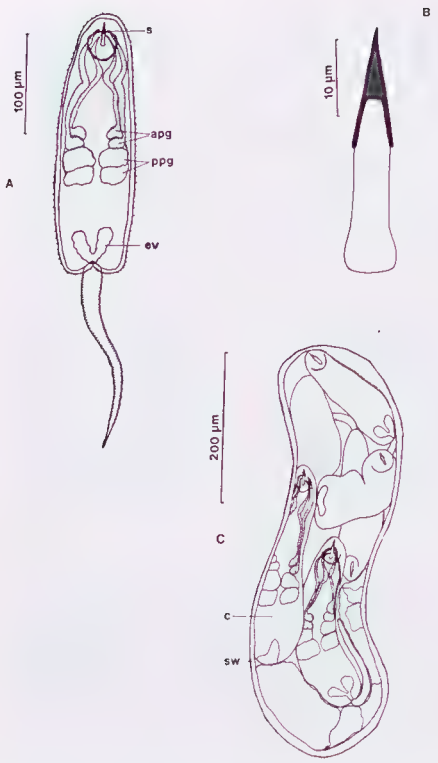

FIG. 3 — Microphallus paragrapsi. *(A) cercaria; (B) dorsal view of stylet; (C) sporocyst (apg = anterior penetration glands, c = cercaria, ev = excretory vesicle, os = oral sucker, ppg = posterior penetration glands, sw = sporocyst wall, s = stylet).*

posterior socket and gradually tapers towards its tip. Tegumental annulations occur along its length. The tail has a length of 170 µm (163–185) and an anterior width of 12 µm (10–15). A large stylet (fig. 3B) is embedded in the dorsal anterior portion of the oral sucker. The anterior one-fifth of the stylet is entirely thickened, the remainder as far as the basal one-eighth is only partially thickened. The stylet measures: length 29 µm (26–31), stylet point 19 µm (18–20) and the stylet base 6 µm (5–7.5). The oral sucker measures 35 µm (32–37) by 32 µm (30–35). Four pairs of unicellular penetration glands with long sigmoidal ducts, open anteriorly at the level of the stylet, about half way along its length. The two posterior pairs are larger. The excretory bladder is large, bilobed and conspicuous when dilated. Details of the excretory ducts and flame cells were not determined.

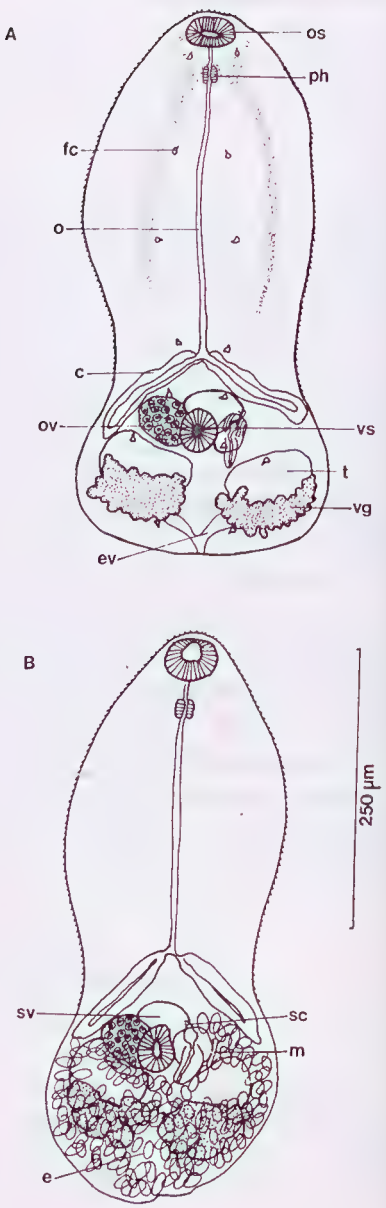

FIG. 4 — Microphallus paragrapsi. *(A) excysted metacercariae from* Philyra laevis*; (B) gravid adult from the gut of* Larus pacificus *(c = cercaria, e = egg, ev = excretory vesicle, fc = flame cell, m = metraterm, mmp = male papilla, o = ovary, os = oral sucker, ph = pharynx, sc = seminal canal, sv = seminal vesicle, t = testis, vg = vitellaria, vs = ventral sucker).*

Metacercaria (figs 1E, 4A)

Mature cysts are round and measure 313 µm (270–353) in diameter. The cyst wall thickness is 48 µm (30–60). Metacercarial cysts removed from the nervous system of *P. laevis* and excysted *in vitro*, are dimensionally and morphologically consistent with the description of *M. paragrapsi* by Smith (1983). The dimensions of worms excysted and flattened under coverslip pressure are presented in table 2. The flame cell formula was tentatively determined to be 2[(2+2)+(2+2)] = 16.

Adult (fig. 4b)

Adult worms removed from the gut of *L. pacificus* are morphologically and dimensionally consistent with the description of *M. paragrapsi* by Smith (1983). Features used to make the determination are: body shape pyriform to elongate spatulate with distinct waist anterior to seminal vesicle; tegumental spines quincuncially arranged, diminishing in size posterior, extending to waist level; tegumental gland cells distributed over anterior body; oral sucker transversely oval to round, mouth subterminal ventral; prepharynx short; oesophageal bifurcation in posterior half of body; caeca relatively short, terminating at midlevel of ventral sucker; ventral sucker round, smaller than oral sucker; testis oval, equal posterolateral; no cirrus pouch, seminal vesicle oval, partly dorsal to ventral sucker; seminal canal leading posteriorly from seminal vesicle to expanded pars prostatica at base of male papilla; prostrate gland cells located between seminal vesicle and male papilla, clustered around seminal canal; everted male papilla tubular, directed posteromedially; ovary oval, contiguous to dextral caecum and testis, dextral and partly dorsal to ventral sucker; vitelline gland cells clustered in compact bunches posterior to each testis; eggs numerous and oval; and excretory vesicle V–shaped, limbs extending to testes. The dimensions of ovigerous worms and a non-ovigerous worm are presented in table 3.

TABLE 2
***Microphallus paragrapsi* metacercariae**

Dimension* (µm)		
Body length	502	(300-750)
Body width	125	(13-168)
Oral sucker length	55	(30-68)
Oral sucker wiodth	60	(34-79)
Prepharynx length	12	(6–26)
Oesophagus length	280	(188–335)
Ovary width	33	(15–56)
Pharynx length	26	(15–34)
Pharynx width	26	(15–34)
Left carcum length	185	(131–262)
Right carcum length	173	(113–262)
Ventral sucker length	58	(38-64)
Right testis width	63	(53–75)
Ventral sucker width	55	(38-60)
Seminal vesicle width	36	(19-51)
Seminal vesicle length	55	(30-78)
Ovary length	53	(26–82)
Left testis length	70	(56–94)
Left testis width	65	(48–94)
Right testis length	72	(52–105)

* Metacercariae, flattened under coverslip pressure, 2 hours after excystment (n = 10).

DISCUSSION

Cysts removed from the nervous system and experimentally excysted metacercariae from *Philyra laevis* are dimensionally and morphologically consistent with the description of *Microphallus paragrapsi* Smith 1983. The location of cysts in *P. laevis* is identical to that recorded by Smith (1983) from the host *Paragrapsus gaimardii*. Furthermore the distributions of *Philyra laevis* and *Paragrapsus gaimardii*, at Great Bay and Pipe Clay Lagoon overlap and both species naturally occur in close proximity to the snail *Assiminea brazieri*. *M. paragrapsi* from the nerves of *P. gaimardii* and cysts found in the nerves of *Philyra laevis* are therefore considered to the the same species. Mature ovigerous worms removed from the gut of the Pacific gull are morphologically and dimensionally consistent with the description of *M. paragrapsi* and are likewise considered to be the same species.

According to Smith (1981) the only other microphallid known to encyst in the nerves of its crustacean intermediate host is *Microphallus pachygrapsi*, a parasite in the crab *Pachygrapsus marmoratus*, on the Mediterranean coast of France. The life history of *M. pachygrapsi* has been described (Prevot 1971, 1974), particularly the mode of penetration and subsequent finding of the encystment site. Penetration by *M. pachygrapsi* occurs through the gills of its crab host and

TABLE 3
Microphallus paragrapsi from the Gut of the Pacific Gull *Larus pacificus*

Dimension*	Ovigerous adults (μm)		Non-ovigerous adult (μm)
Body length	513	(450–560)	460
Body width	186	(175–200)	193
Oral sucker length	43	(40–50)	43
Oral sucker width	46	(43–50)	46
Prepharynx length	19	(7.5–35)	22
Oesophagus length	195	(158–210)	179
Pharynx length	25	(20–28)	23
Pharynx length	23	(20–25)	22
Left caecum length	112	(103–120)	98
Right caecum length	105	(100–112)	100
Ventral sucker length	40	(28–45)	38
Ventral sucker width	35	(33–43)	36
Seminal vesicle length	44	(38–50)	40
Seminal vesicle width	35	(30–50)	30
Ovary length	45	(35–60)	40
Ovary width	41	(35–43)	35
Sample size	7		1

* Specimens fixed, under coverslip pressure.

encystment takes place within the nerves of the legs and claws. The cercariae travel by way of the circulatory system. Some cercariae are carried by the sternal artery into the limb arteries. At the junction between the basipodite and ischiopodite of the periopods, the appendiculate nerve branches and passes close to the blood capillaries. At this point cercariae penetrate the nerve and ascend to variable sites. Cercariae travelling by other arteries may relocate by migration through the sinuses. As the site of external penetration and encystment site of both *M. paragrapsi* and *M. pachygrapsi* are identical and the species are closely related, it is likely the mode of site-finding in both species is similar. This would account for the presence of post-cercariae in the body cavity of *Philyra laevis* during experimental infection.

Encystment of *M. paragrapsi* occurred within four days at 30°C. High temperatures may be recorded in rock pools but this is unlikely to be a continuous environmental temperature for crabs. Generally, the development rate of larval trematodes increases with increase in temperature, so under natural conditions it is expected that post-cercariae take longer than four days to encyst. Prevot (1974) found *M. pachygrapsi* took a variable length of time to encyst, ranging between one and seven days.

Results from the survey of crabs at Great Bay suggest a seasonal component to infection by *M. paragrapsi*. A peak in the degree of infection (mean number of cysts per crab) occurred in June, as did the percentage of immature cysts per crab. Seasonal variations in infection have been recorded for many crustacean hosts (Yamaguti 1975) and for molluscan and vertebrate hosts (Smith 1971, Bakke 1972). A variation in feeding habits and/or frequency of occurrence of the vertebrate host at study sites may be sufficient to produce subsequent variation in the infection levels of the primary and intermediate hosts. Pacific gulls are found only in southern Australia and do not undertake seasonal migrations (Tuck & Heinzel 1980), therefore any seasonal variation in occurrence at study sites must be on a local scale.

Sufficient information is available to speculate on the geographical distribution of the developmental stages of *M. paragrapsi*. Trematodes show a high degree of host specificity at the primary-host level and individual species of

trematodes tend to be restricted to molluscan species of a single genus (Erasmus 1972, Ewers 1964). If *M. paragrapsi* is species-specific at the molluscan host level, then its distribution would be confined to southern Australian waters, the known distribution of *A. brazieri*.

The life history of *M. paragrapsi* can be postulated from the results of this study. The life history involves a three-host cycle: molluscan primary host, *Assiminea brazieri*; crustacean intermediate hosts, *Philyra laevis* and *Paragrapsus gaimardii*; and the final vertebrate host *Larus pacificus*. Adult worms infect the posterior gut of the Pacific gull. When eggs are shed they pass out in the bird's faeces. Infection of the snail host will result from ingestion of the egg by a browsing snail and subsequent hatching of the egg containing a miracidium. Development and multiplication take place in the hepatopancreas of the snail. Cercariae develop within sporocysts; mature cercariae emerge from the snail host and have a brief life-span swimming freely in the sea. By chance cercariae may be drawn into the branchial chamber of the crab host. On contact with the gill surface the cercariae penetrate the crab and subsequently encyst within the nervous system. When the infected crab is ingested by a Pacific gull, metacercariae excyst and become sexually mature in the posterior gut of the bird, thus completing the life history.

ACKNOWLEDGEMENTS

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REFERENCES

BAKKE, T.A., 1972: Studies on the helminth fauna of Norway XXII. The common gull, *Larus canus* L., as final host for Digenea (Platyhelminthes). *Norw. J. Zool.* 20: 165–188.

ERASMUS, D.A., 1972: *THE BIOLOGY OF TREMATODES*. Edward Arnold (Pub.) Limited, London.

EWERS, W.H., 1964: An analysis of the molluscan hosts of the trematodes of birds and mammals and some speculation on host specificity. *Parasitology* 54: 571–578.

PREVOT, G., 1971: Contribution a l'étude des Microphallidae Travassos, 1920 (Trematoda). Cycle évolutif de *Microphallus pachygrapsi* Deblock et Prevot, 1969 parasite du Goé land a pieds jaunes (*Larus argentatus*). *Ann. Parasitol. (Paris)* 46: 453–461.

PREVOT, G., 1974: Recherches sur le cycle biologique et l'écologie de quelques trematodes nouveaux parasites de *Larus argentatus Machaellis naumann dans le midi de la France*. Unpubl. D. es-Sc. thesis, Univ. de Droit, d'Economie et des Sciences d'Aix-Marseille.

SMITH S.J., 1971: A study of some larval digenetic trematodes infecting invertebrates in Calvert's Lagoon. Unpubl. B.Sc. Hons. thesis, Univ. Tasm.

SMITH, S.J., 1981: The trematode fauna of a brackish lagoon in Tasmania. Unpubl. Ph.D. thesis, Univ. Tasm.

SMITH, S.J., 1983: Three new species and a new record of microphallid trematodes from Tasmania, with observations on their in vitro development. Pap. Proc. *R. Soc. Tasm.* 117: 105–123.

TUCK, G.S. & HEINZEL, H., 1980: *A FIELD GUIDE TO THE SEABIRDS OF AUSTRALIA AND THE WORLD*. Collins, Sydney.

YAMAGUTI, S., 1975: *A SYNOPTIC REVIEW OF LIFE HISTORIES OF DIGENETIC TREMATODES IN VERTEBRATES*. Keigaku Publishing Company, Tokyo.

(accepted 13 June 1988)

A DESCRIPTION OF THE HUON PINE (*LAGAROSTROBOS FRANKLINII* (HOOK. F.) C.J. QUINN) FORESTS OF THE PRINCE OF WALES AND KING BILLY RANGES

by Neil Gibson

(with two tables and two text-figures)

GIBSON, N., 1988 (31:x): A description of the Huon pine (*Lagarostrobos franklinii* (Hook. f.) C.J. Quinn) forests of the Prince of Wales and King Billy Ranges. *Pap. Proc. R. Soc. Tasm.* 122(2): 127–133. ISSN 0080–4703.
Department of Geography and Environmental Studies, University of Tasmania, G.P.O. Box 252C, Hobart, Tasmania, Australia 7001; formerly National Parks and Wildlife Service, Tasmania.

The large non-riverine Huon pine forests of the Prince of Wales and King Billy Ranges probably represent glacial refugia. Both are of the implicate rainforest type and both show changes in dominance and species composition of tree and understorey species with altitude. On the Prince of Wales Range, Huon pine dominates the forest over an altitudinal range of 320 m. On the King Billy Range, Huon pine dominates the lower 180 m while the upper 100 m is dominated by King Billy pine. This difference may be due to dispersal rates, geology or climatic preference. The upper slopes of the Prince of Wales Range carry the only known examples of a Huon pine–dwarf leatherwood dominated forest. Both the Prince of Wales and King Billy Ranges are of high conservation and scientific value.
Key Words: Huon pine, King Billy pine, altitude, glacial refugia, Tasmania.

INTRODUCTION

Huon pine (*Lagarostrobos franklinii* (Hook. f.) C.J. Quinn) is a slow-growing endemic gymnosperm largely restricted to the western and southern river systems of Tasmania with a total extent of less than 3000 ha (Gibson 1986). Despite nearly 200 years of exploitation for its superb timber, knowledge of the ecology of this species has been rudimentary until recently (Pedley *et al.* 1980, Davies 1983, Francey *et al.* 1984, Read 1985, Gibson 1986).

Huon pine was apparently more widespread in the past (Colhoun & van de Geer 1986, 1987). It appears to be still expanding its range following amelioration of the climate after the Last Glacial, 10 000–12 000 years ago (Gibson 1986). Despite its slow rate of dispersal from rivers (Gibson 1986), vegetative reproduction is prolific. The species is also highly sensitive to fire and can be eliminated from areas by a single fire event. These features, coupled with frequent high energy flooding of the rivers on which it occurs, largely explain its riverine distribution.

Three large stands (>200 ha) of non-riverine Huon pine occur on the King Billy Range, the Prince of Wales Range and the Teepookana Plateau above the King River. These three stands account for more than 40% of the total extent of Huon pine. The stands on the Prince of Wales and King Billy Ranges are dominated by the implicate Huon pine rainforest association while the Teepookana stand consists largely of thamnic rainforest communities (Jarman *et al.* 1984, Gibson, unpubl. data). The extent of these stands and the slow spread of Huon pine from river banks indicate that the stands are glacial refugia.

All three stands have been logged to some extent. On the Prince of Wales Range damage has been restricted to a narrow band along the Denison River. The King Billy Range stand has been more heavily logged. Disturbance, however, is very localised due to the highly selective nature of pre-1950 logging operations. The Teepookana Plateau stand has been heavily disturbed by modern logging and roading operations. The aim of the present study is to describe the floristic and altitudinal gradients found on two transects through largely intact Huon pine stands of the Prince of Wales and King Billy Ranges.

STUDY AREAS

The Prince of Wales Range (42°37'S, 145°55'E) is about 14 km NNW of Strathgordon in southwestern Tasmania. The range runs approximately N–S and the eastern side drains into the

Denison River. The entire region is underlain by Precambrian metaquartzites with some Holocene alluvium in the valley (Department of Mines 1975). A section of the eastern side of the range, 4 km above the gorge, has a Huon pine dominated forest from river level (at 120 m) to 440 m a.s.l. Above this forest is extremely thick scrub dominated by *Agastachys odorata* and *Acacia mucronata*, up to the ridge line at 520 m a.s.l.

The King Billy Range (42°35'S, 145°40'E) lies 3 km Sw of the junction of the Gordon and Franklin Rivers. The range is crescent shaped with the main axis running E–W, the arms of the crescent stretch away to the south for about 2 km. The southern slopes drain into the Sprent River. The lower slopes of the range are composed of Precambrian metaquartzites while the upper slopes are of Ordovician siliceous conglomerates, sandstones and siltstones (Department of Mines 1975). Almost the entire southern slopes carry either Huon pine or King Billy pine (*Athrotaxis selaginoides*) dominated rainforests. Huon pine is dominant on the lower slopes from river level (at 140 m) to about 320 m a.s.l. and King Billy pine on the upper slopes from 320 m to the ridgeline at 420 m a.s.l.

Both areas lie within the cold humid climatic zone of Gentilli (1972) and are expected to have rainfalls of the order of 2500 mm (Bureau of Meteorology unpublished data). Both ranges have uniformly steep slopes averaging 50–60% and increasing to 75% for short distances.

METHODS

On the Prince of Wales Range seven subjectively located plots were established from river level to the scrub zone to encompass the floristic variation found over the 330 m altitude of the transect. Except for plot 1 (at river level) all plots were circular in shape. Initially the circumference of all individuals between 10 mm and 100 mm diameter at breast height (dbh) were measured in a plot of 10 m diameter. Then the plot diameter was increased to 20 m diameter and the circumferences of all individuals greater than 100 mm dbh were recorded. In addition species presence/absence, structure and cover data were collected for all vascular plants. The plot along the river was rectangular in shape, 31.5 m x 10 m, to optimally sample the riverine community. A smaller plot of 10 m x 8 m was established within the larger plot. The long axis of the plot ran parallel to the river edge. the same methods were employed on the King Billy Range where six plots were established along a transect from the river to the ridge top (140 m–420 m a.s.l.). The altitude of the plots was estimated to ±20 m using clinometer measurements to the surrounding topography. The slopes of plots were also determined using the clinometer.

Floristic data were ordinated using detrended correspondence analysis (Hill & Gauch 1980), one of the least distorting of the indirect gradient methods currently available (Brown *et al.* 1984). Minchin (1987) has reported that this method may result in marked distortions and care needs to be used in interpreting these ordinations.

Nomenclature follows Curtis (1963, 1967), Curtis & Morris (1975), Willis (1970) and Jones & Clemesha (1981), unless otherwise indicated. Vegetation terminology follows Jarman *et al.* (1984).

RESULTS AND DISCUSSION

Both forests are classified as implicate Huon pine rainforest and both show a marked altitudinal variation in species composition (figs 1, 2). Overall, both transects show similar species compositions, 50 species occurring on the Prince of Wales transect and 49 on the King Billy Range transect (Appendix 1). However, there is marked contrast in species dominance and biomass, especially in the higher altitude plots (figs 1, 2; tables 1, 2).

The forest on the Prince of Wales Range is dominated by Huon pine from river level to the scrubline, covering 320 m in altitude (fig. 1, table 1). *Nothofagus cunninghamii* extends to above the scrubline with a fairly consistent dominance of 15–20%. *Atherosperma moschatum* and *Phyllocladus aspleniifolius* tend to be more patchy in their distribution. *Eucryphia lucida* is a dominant species at lower altitudes but drops out and is replaced by *E. milliganii* (dwarf leatherwood) in plots 5 and 6. The latter species exhibits an extremely small leaf form in this area compared with other (high or low altitude) sites in southwestern Tasmania. Total tree density varies between 10–17 trees per 100 m^2, while mean diameters and basal areas show a marked decrease at higher altitudes (table 1). Huon pine shows a similar individual trend. Above the scrubline, *Acacia mucronata* and *Agastachys odorata* are dominant tree species along with some coppice *Nothofagus cunninghamii* and *E. milliganii*. A few trees of *Phyllocladus aspleniifolius* are also present. No evidence of live or dead Huon pine was

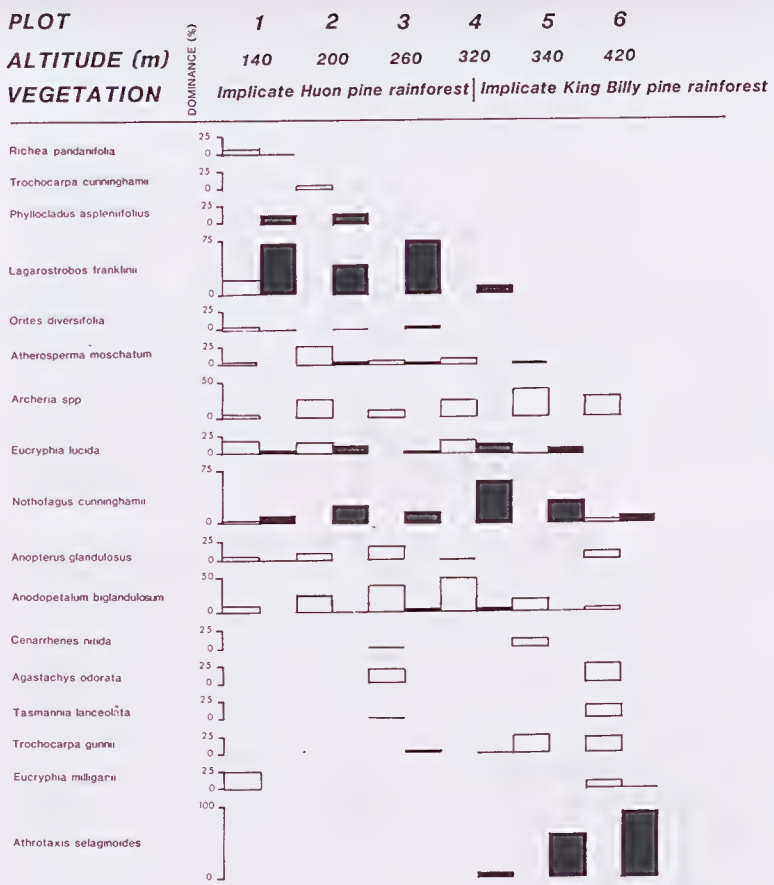

FIG. 1 — Patterns of dominance of tree species (■) and shrubs/sapling species (□) on the Prince of Wales Range transect (relative basal area used as the dominance measure).

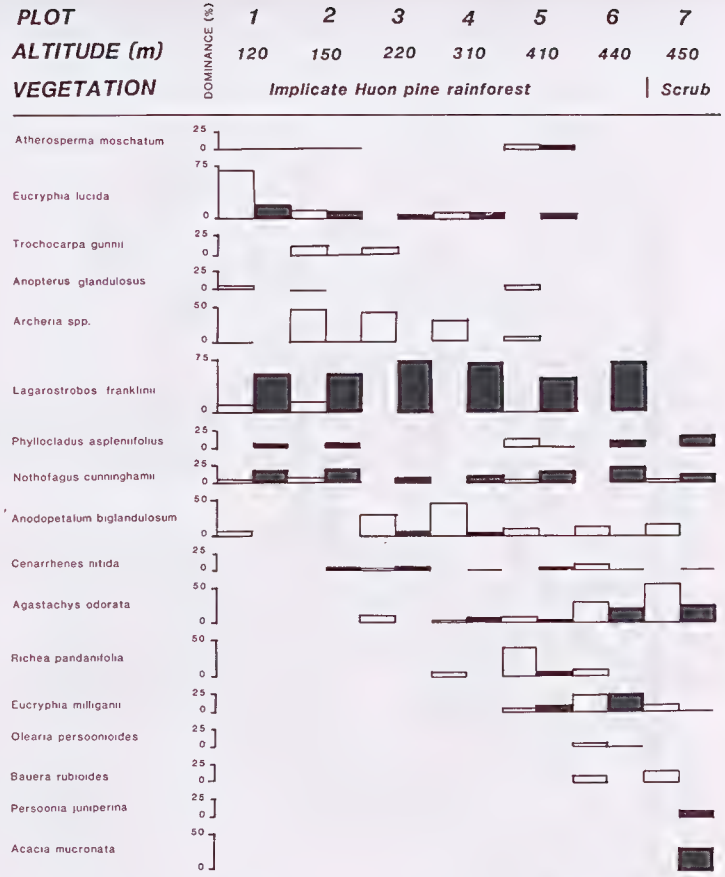

FIG. 2 — Patterns of dominance of tree species (■) and shrubs/sapling species (□) on the King Billy Range transect (relative basal area used as the dominance measure).

TABLE 1
Variation over a Transect on the Prince of Wales Range

Parameter	1	2	3	4	5	6	7
Altitude (m a.s.l.)	120	150	220	310	410	440	450
Vegetation	implicate Huon pine rainforest						scrub
Mean dbh (mm)	301	256	301	285	213	179	207
Tree density (per 100 m^2)	11.8	15.0	13.4	10.2	16.9	15.0	5.1
Basal area (m^2)	0.8430	0.7713	0.9504	0.6482	0.6002	0.3754	0.1710

TABLE 2
Variation over a Transect on the King Billy Range

Parameter	1	2	3	4	5	6
Altitude (m a.sl.)	140	200	260	320	340	420
Vegetation	implicate Huon pine rainforest			implicate King Billy pine rainforest		
Mean dbh (mm)	268	258	344	262	396	733
Tree density (per 100 m^2)	9.2	13.1	12.1	13.4	9.9	3.5
Basal area (m^2)	0.5217	0.6735	1.1225	0.7260	1.2213	1.4756

found above the scrubline where both tree density and biomass are low (table 1).

The riverine plot shows a high species diversity with 22% of species being restricted to it. There are changes in both dominance and species composition in the shrub/sapling class (>10 mm, <100 mm dbh) with altitude (fig. 1). *Eucryphia lucida* is very common in plot 1. This results in part from disturbance due to logging of Huon pine some 15–20 years previously. In the lower part of the transect *Archeria eriocarpa* and *A. hirtella* are the dominant species. These are replaced by *Anodopetalum biglandulosum*, *Richea pandanifolia* and finally *Agastachys odorata*. Only five sapling class (10–100 mm dbh) Huon pines are found over the entire transect and all but one of these occurs in plots 1 and 2. Above the scrubline *Agastachys odorata* accounts for more than 50% of the shrub/sapling basal area. There is a marked floristic change at the scrubline with 22% of the total recorded species being confined to the top forest plot (plot 6) and scrub plot (plot 7). Only one species, *Nothofagus cunninghamii*, occurs in all plots although a further 16% of species occurs in all the forest plots.

The indirect gradient analysis confirmed these results and showed altitude, or more precisely, those environmental factors which change with altitude, to be the major underlying environmental gradient. The first axis of the ordination is significantly correlated with altitude ($r = 0.772$, $P < 0.05$).

In contrast, the rainforest on the southern slopes of the King Billy Range is dominated by Huon pine to 320 m a.s.l., above which King Billy pine assumes almost complete dominance (fig. 2, table 2). *Nothofagus cunninghamii* is the major sub-dominant tree species, becoming dominant temporarily at the ecotone between the two pine species (fig. 2). *Eucryphia lucida* is present at low incidence in all quadrats except for plot 6 where it is replaced by *E. milliganii*. *Phyllocladus aspleniifolius* is only common in the lower sections of the transect. Tree density of the Huon pine forest is slightly lower than of the Prince of Wales Range, but basal areas show a comparable range (table 2). Extensive selective logging for Huon pine has taken place throughout the lower slopes. This pining probably dates from 1930–40 (Forestry Commission, unpubl. data). The implicate King Billy pine forest (plots 5, 6) has an extremely dense understorey with prolific moss growth 5 m up the trees. The high degree of dominance shown by *Athrotaxis* in the higher altitude plots (fig. 2) is due to large tree size (>1.5 m dbh) rather than high density (table 2). The overall tree density in the

King Billy pine forest decreases with altitude while basal area dramatically increases (table 2).

The riverine plot shows high species diversity with the occurrence of 84% of species; 31% of species being restricted to this plot. Fourteen per cent of species occur in all plots, while a further 6% occur in all but the highest. Eight per cent of species only occur in the high altitude King Billy pine forest (plots 5, 6).

Whilst change in dominance and species composition of the shrub/sapling class does occur (fig. 2), it is not as great as that seen on the Prince of Wales Range (fig. 1). *Richea pandanifolia* and *Trochocarpa cunninghamii* are restricted to the bottom of the transect. *Eucryphia lucida* and *Atherosperma moschatum* extend to plot 5, whilst *Archeria* spp. and *Anodopetalum biglandulosum* are ubiquitous dominant understorey species. *Agastachys odorata*, *Cenarrhenes nitida* and *Tasmannia lanceolata* occur at the higher altitudes. *Eucryphia milliganii* occurs in the ridge plot but also in significant numbers at the river. Huon pine saplings only reach significant numbers in the riverine plots.

Indirect gradient analysis again shows that altitude is the major underlying environmental gradient, the first axis of the ordination being significantly correlated with altitude ($r = -0.732$, $P < 0.05$).

CONCLUSIONS

The two areas offer interesting comparisons and contrasts. Both transects show changes in dominance and species composition of both tree and understorey species. Tree species replacement is better developed on King Billy Range and shrub and sapling species replacement is better developed on Prince of Wales Range. The Huon and King Billy pine forests of the King Billy Range show marked differences in both tree density and basal area, while tree density and basal area figures are comparable between the Huon pine forests of the two stands.

There is an interesting contrast in the altitudinal range of Huon pine between the two transects. On the Prince of Wales Range, Huon pine is dominant over 320 m altitude (from 120–440 m a.s.l.) whilst on the King Billy Range it is dominant over 180 m altitude (from 140–320 m a.s.l.) with the upper 100 m of altitude being dominated by King Billy pine. Although occasional individuals of both pine species occur in the other's habitat, the ecotone between the forests is very narrow, occurring over some 30 m in altitude. The subdominant canopy species *Eucryphia milliganii* replaces *E. lucida* at higher altitudes on the Prince of Wales Range and this transition occurs at the same altitude on the King Billy Range. The question arises as to why Huon pine is replaced on one mountain slope whilst other species show similar distribution patterns on both transects.

There are at least three possible explanations for this replacement. Huon pine may still be expanding its range upslope on the King Billy Range. If this is the case then the process must be extremely slow. The ecotone between the two pine forests is narrow and there is no evidence of old King Billy pine on the lowers being replaced by Huon pine migrating upslope, nor vice versa. Sapling recruitment of Huon pine is also very low in the higher altitude plots, all of which suggest a stable boundary.

The distribution pattern of the pines may be related to geology, since there is a major boundary between Precambrian and Ordovician rocks occurring approximately at the altitude of the ecotone. This may explain the much higher biomass found in the King Billy pine forest. The third possibility is that the pines' distribution may be related to climate. The upper slopes of the King Billy Range are very moist with moss extending 5 m or more up trees. This situation may reflect a "cloud forest" environment preferentially suiting *Athrotaxis selaginoides*. These hypotheses could be tested by reciprocal transplant experiments.

The *Eucryphia milliganii–Lagarostrobos franklinii* dominated forests from the upper slopes of the Prince of Wales Range appear to be unique; this being the only known location where there is a significant overlap of their ranges.

The Prince of Wales and the King Billy ranges are of high conservation value and scientific interest given both their floristics and the large extent of the stands. Gibson (1986) considered implicate Huon pine rainforest to be poorly reserved on a state-wide basis. The lower slopes of the King Billy Range have been extensively logged for Huon pine with pre-1950 technology. Although local disturbance in this forest is obvious, the highly selective nature of the logging has not significantly impaired the conservation value of the stand. Both these areas have had a fire-free period of at least 600 years (Gibson 1986). These two stands account for more than 20% of the known extent of Huon pine and probably represent glacial refugia. The only comparable area of non-riverine Huon pine rainforest occurs on the Teepookana Plateau which has been heavily disturbed by modern logging and roading.

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REFERENCES

BROWN, M.J., RATKOWSKY, D.A. & MINCHIN, P.R., 1984: A comparison of detrended correspondence analysis and principal co-ordinates analysis using four sets of Tasmanian vegetation data. *Aust. J. Ecol.* 9: 273–279.

COLHOUN, E.A. & VAN DE GEER, G., 1986: Holocene to Middle Last Glaciation vegetation history at Tullabardine Dam, western Tasmania. *Proc. R. Soc. Lond.* B229: 177–207.

COLHOUN, E.A. & VAN DE GEER, G., 1987: Vegetation history and climate before the maximum of the Last Glaciation at Crotty, western Tasmania. *Pap. Proc. R. Soc. Tasm.* 121: 69–74.

CURTIS, W.M., 1963: *THE STUDENT'S FLORA OF TASMANIA, PART 2.* Government Printer, Tasmania.

CURTIS, W.M., 1967: *THE STUDENT'S FLORA OF TASMANIA, PART 3.* Government Printer, Tasmania.

CURTIS, W.M. & MORRIS, D.I., 1975: *THE STUDENT'S FLORA OF TASMANIA, PART 1.* Second edition. Government Printer, Tasmania.

DAVIES, J., 1983: Huon pine survey 1983. *Tech. Rep.* 83/2. Tasm. Natl Pks Wildl. Serv.

DEPARTMENT OF MINES, 1975: 1:250,000 Tasmanian Geological Atlas Series Sheet SK55-5. Department of Mines, Hobart.

FRANCEY, R.J., BARBETTI, M., BIRD, T. *et al.*, 1984: Isotopes in tree rings. *CSIRO Div. Atmos. Res. Tech. Pap.* 4: 1–86.

GIBSON, N., 1986: Conservation management of Huon pine in Tasmania. *Tech. Rep.* 86/3. Tasm. Natl Pks Wildl. Serv.

HILL, M.O. & GAUCH, H.G., 1980: Detrended correspondence analysis: an improved ordination technique. *Vegetatio* 10: 47–58.

JARMAN, S.J., BROWN, M.J. & KANTVILAS, G., 1984: *RAINFOREST IN TASMANIA.* National Parks & Wildlife Service, Tasmania.

JONES, D.L. & CLEMESHA, S.C., 1981: *AUSTRALIAN FERNS AND FERN ALLIES.* Second edition. Reed, Sydney.

MINCHIN, P.R., 1987: An evaluation of the relative robustness of techniques for ecological ordination. *Vegetation* 69: 89–107.

PEDLEY, J., BROWN, M.J. & JARMAN, S.J., 1980: A survey of Huon pine in the Pieman River State Reserve and environs. *Tech. Rep.* 80/2. Tasm. Natl Pks Wildl. Serv.

READ, J., 1985: Photosynthetic and growth responses to different light regimes of the major canopy species of Tasmanian cool temperate rainforest. *Aust. J. Ecol.*, 10: 327–334.

WILLIS, J.H., 1970: *A HANDBOOK OF PLANTS IN VICTORIA. Vol. I Ferns, Conifers and Monocotyledons.* Melbourne University Press.

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APPENDIX
Vascular Plants on Transects on the Prince of Wales and King Billy Ranges

Plant species	Location	
	PWR*	KBR*
PTERIDOPHYTA		
Blechnaceae		
Blechnum minus	+	
Blechnum nudum	+	
Blechnum wattsii	+	+
Davalliaceae		
Rumohra adiantiformis		+
Gleicheniaceae		
Gleichenia dicarpa	+	+
Sticherus tener	+	+
Grammitidaceae		
Grammitis billardieri	+	+
Microsorium diversifolium		+
Hymenophyllaceae		
Hymenophyllum australe	+	+
Hymenophyllum rarum	+	+
Psilotaceae		
Tmesipteris billardieri		+
GYMNOSPERMS		
Podocarpaceae		
Lagarostrobos franklinii	+	+
Taxodiaceae		
Athrotaxis selaginoides		+
DICOTYLEDONS		
Araliaceae		
Pseudopanax gunnii		+
Compositae		
Olearia persoonioides	+	+
Cunoniaceae		
Anodopetalum biglandulosum	+	+
Bauera rubioides	+	+
Elaeocarpaceae		
Aristotelia peduncularis	+	+
Epacridaceae		
Archeria eriocarpa	+	+
Archeria hirtella	+	+
Cyathodes juniperina	+	+
Epacris serpyllifolia	+	
Monotoca glauca	+	
Prionotes cerinthoides	+	+
Richea pandanifolia	+	+
Sprengelia incarnata		+
Trochocarpa cunninghamii	+	+
Trochocarpa gunnii	+	+
Escalloniaceae		
Anopterus glandulosus	+	+
Eucryphiaceae		
Eucryphia lucida	+	+
Eucryphia milliganii	+	+
Fagaceae		
Nothofagus cunninghamii	+	+
Mimosaceae		
Acacia mucronata	+	+
Monimiaceae		
Atherosperma moschatum	+	+
Myrtaceae		
Leptospermum lanigerum	+	
Leptospermum scoparium		+
Oxalidaceae		
Oxalis corniculata	+	
Pittosporaceae		
Billardiera longiflora	+	
Plantaginaceae		
Plantago paradoxa	+	
Proteaceae		
Agastachys odorata	+	+
Cennarrhenes nitida	+	+
Lomatia polymorpha		+
Orites diversifolia		+
Persoonia gunnii	+	
Telopea truncata		+
Ranunculaceae		
Clematis aristata	+	
Rubiaceae		
Coprosma nitida		+
Coprosma quadrifida	+	+
Rutaceae		
Phebalium squameum	+	
Violaceae		
Viola hederacea	+	+
Winteraceae		
Tasmannia lanceolata	+	+
MONOCOTYLEDONS		
Cyperaceae		
Gahnia grandis	+	+
Tetraria capillaris		+
Uncinia spp.	+	
Gramineae		
Microlaena tasmanica		+
Microlaena stipoides	+	
Iridaceae		
Diplarrena latifolia	+	+
Libertia pulchella	+	+
Juncaceae		
Juncus spp.	+	
Liliaceae		
Astelia alpina		+
Restionaceae		
Calorophus elongatus	+	
Calorophus sp.	+	+
Restio tetraphyllus		+

* PWR = Prince of Wales Range, KBR = King Billy Range.

THE VOCAL REPERTOIRE OF THE YELLOW-THROATED HONEYEATER, *LICHENOSTOMUS FLAVICOLLIS*

by Penelope J. Bruce

(with one table and two text-figures)

BRUCE, P.J., 1988 (31:x): The vocal repertoire of the yellow-throated honeyeater, *Lichenostomus flavicollis*. *Pap. Proc. R. Soc. Tasm.* 122 (2): 135–138. ISSN 0080–4703. Zoology Department, University of Queensland, St Lucia, Qld, Australia 4067; formerly Department of Zoology, University of Tasmania.

Vocalisations of the yellow-throated honeyeater were recorded at Mount Nelson, and throughout northern and eastern Tasmania. Territorial songs, calls associated with territorial disputes, and calls given by parents and young during the breeding cycle are described.

Key Words: vocalisations, songs, call, yellow-throated honeyeater, Tasmania.

INTRODUCTION

The yellow-throated honeyeater *Lichenostomus flavicollis* is endemic to Tasmania. It belongs to a group of monogamous, non-cooperative honeyeaters that defend all-purpose territories all year round. The female is apparently territorial only during the breeding season and, in some cases, returns to the same territory in successive years (Bruce & Wilson, unpubl. data). Throughout the year males defend a territory of around 0.5 ha. A single female and fledglings are resident on the territory during the breeding season (Bruce 1984).

Although Littler (1903) described the yellow-throated honeyeater as possessing vocalisations practically limited to "a loud whistle-like note often repeated", Anon. (1976) and Pizzey (1980) describe a variety of songs and calls. This paper details the different vocalisations of the yellow-throated honeyeater and includes notes on the contexts in which they occur.

METHODS

Vocalisations were recorded in the field between February and October 1984. Most of the work was conducted in the University Reserve at Mount Nelson, although recordings were made throughout northern and eastern Tasmania. Eight birds were colour banded at Mount Nelson, including four males and one female that were residents on five different territories. Recordings were made with a Sony TC-D5 M cassette recorder coupled with a pre-amplifier, and a Nakamichi condensor microphone with a shotgun capsule attachment. Careful notes were taken on the behaviour of focal birds.

Throughout this paper the following definitions will apply. A syllable is the shortest continuous segment of a vocalisation. Interval refers to the distance in time between two syllables and duration is the length of the syllables. Harsh vocalisations usually consist of multiples of pure tones. The lowest of these is called the fundamental frequency and the higher frequencies are called the harmonics of the syllable.

RESULTS AND DISCUSSION

Territorial Songs

Three types of song were used in the territorial advertisement and/or mate attraction. These were based on a series of short, repeated syllables, the loudest being audible over a distance of half a kilometre in ideal conditions. The usual position for the performance of the songs was in a conspicuous place at the top of eucalypts, dead branches being particularly favoured. If a male heard a song from a nearby bird, it would work its way up to the top of a tree in its own territory, singing at regular intervals, and finally remain at the top singing. The songs were characteristically sung in response to a nearby male's song. Table 1 describes the frequency and temporal features of these songs.

TABLE 1

Frequency and Temporal Characteristics of Territorial Songs at Mount Nelson

Note that the breeding song consists of two-syllable song phrases. The duration and frequency columns contain two values referring to these syllables in order.

		Song		
		Non-breeding	**Trill**	**Breeding**
No. syllables —	mean	4	15	7
	range	1–10	5–>100	2–12
Interval (ms) —	phrase	–	–	419
	syllable	590	447	101
Duration (ms) —	syllable	36.6	36	60, 150
Frequency (kHz) —	maximum	1.9	1.8	2.9, 2.1
	minimum	1.3	1.3	0.92, 0.99
	range	0.8–2.8	0.8–2.0	0.6–3.3
No. songs sampled		52	4	75

Non-breeding Song (Fig. 1A)

This song has been described as the "tonk" call (Anon. 1976). It is used throughout the year by males. Soft non-breeding songs were occasionally heard from females. Robinson (1949) states that in birds that pair for life and hold permanent territories, both sexes tend to be equally vocal. This was not the case with the yellow-throated honeyeater, however it is uncertain whether these birds pair for life.

Trill Song (Fig. 1B)

The trill song was present all year. It was occasionally preceded by an aggressive call and, from about February to March, by one or two "tonk" syllables. This song usually followed a territorial boundary dispute.

Breeding Song (Fig. 1C)

This song was introduced by the male at the beginning of the breeding season. The stimulus for the song was probably the arrival of females in the territory. The dates that the song was first heard in different study areas were: Mount Nelson — 18 June, Nunamara — 30 June, Reedy Marsh — between 23 July and 20 August, and Underwood — between 1 July and 20 August. The song varied between local populations from a two-syllable "de-witt" to three- and four-syllable songs (Bruce 1987).

Aggressive Call

This harsh call was used by the male and female before and after boundary disputes, in response to nearby song, in interspecific aggression and to the author around the nest site. In one case it continued for 12 minutes. The fundamental frequency of this call was around 1 kHz with harmonics at 2, 4 and 8 kHz. An amplitude emphasis was present at 4 kHz.

Interaction Call

The interaction call was always associated with physical confrontation in territorial boundary disputes. It was a high pitched, harsh call that consisted of rapidly repeated syllables. Two typical postures adopted during such interactions are

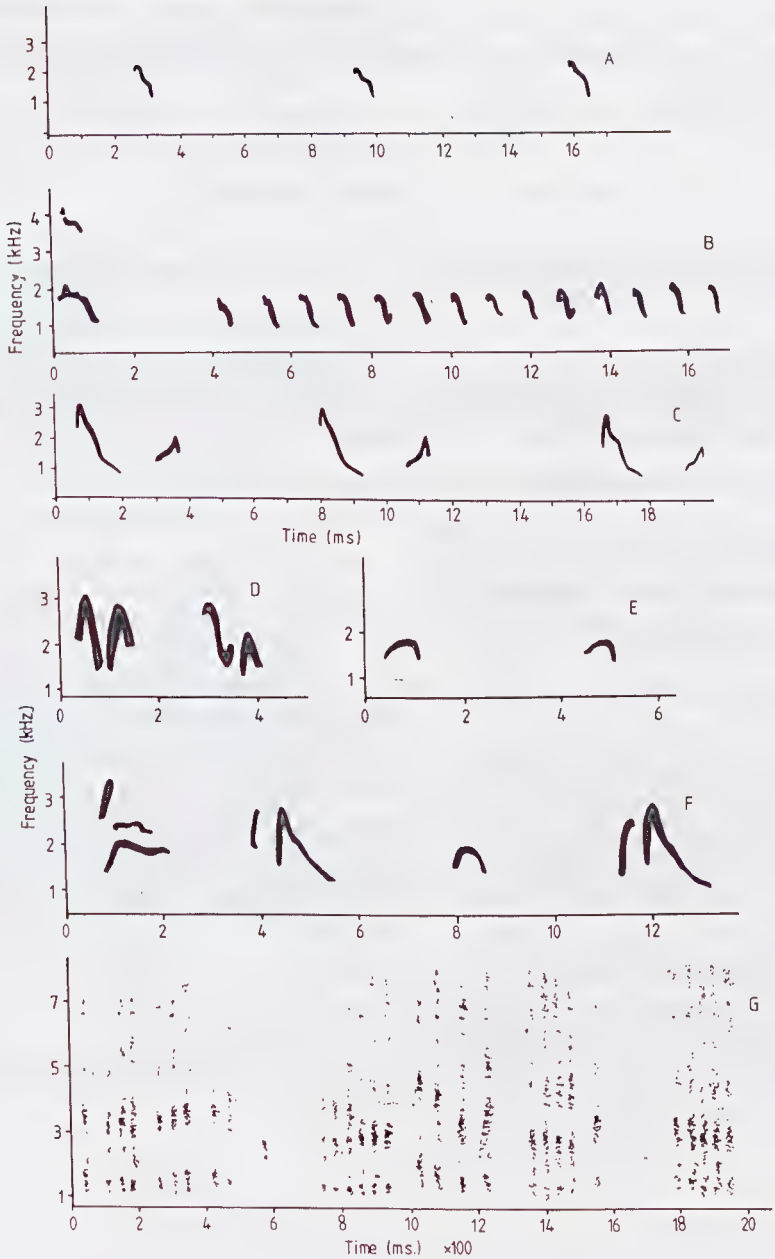

FIG. 1 — Vocalisations of the yellow-throated honeyeater at Mount Nelson. (A) non-breeding song; (B) trill song with a "tonk" preceding it; (C) breeding song; (D) "cheep" call of the nestlings and fledglings; (E) "cheep" call of the female; (F) call of the adult female on arrival at the nest with food; and (G) call of the adult female when she attempted to collect hair from the author's head.

FIG. 2 — Postures associated with the interaction call.

shown in figure 2. The fundamental frequency was at 2 kHz, with harmonics at 4, 8 and 16 kHz. An amplitude emphasis occurred at 4 kHz.

Nest Distraction Display

A harsh squeal-like call given by the male during the nest distraction display. This display consisted of flapping the wings in the undergrowth about 5 m from the nest, or running along the ground while alternatively flapping the wings.

Calls used by the Nestling and Fledglings

Figure 1D shows the "cheep" call given by nestlings and fledglings whilst begging for food. A second call was used by the nestlings from the time the female landed near the nest to when she left. This was a harsh call, containing harmonics, but was shorter in duration than aggressive and interaction calls.

Calls used by the Female

Figure 1E shows the "cheep" call used by the female when chased from a territory and when the male showed driving behaviour towards her. Figure 1F is a call used by the female when she attempted to collect hair from the author's head. Note that this call included a soft version of the Mount Wellington breeding song (Bruce 1987) alternated with the "cheep" call. Figure 1G is a call used when the female approached the nest to feed the young. The male also used this call when feeding the fledglings.

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REFERENCES

ANON., 1976: *COMPLETE BOOK OF AUSTRALIAN BIRDS*. Readers' Digest, Sydney.

BRUCE, P.J., 1984: The song and behaviour of the yellow-throated honeyeater *Lichenostomus flavicollis*, Vieillot 1813. Unpubl. B.Sc. Hons thesis, Univ. Tasm.

BRUCE, P.J., 1987: Spatial and individual variation in the song of the yellow-throated honeyeater, *Lichenostomus flavicollis*. *Emu* 88: 65–69.

LITTLER, F.M., 1903: Notes on some birds peculiar to Tasmania. *Emu* 3: 81–89.

PIZZEY, G., 1980: *A FIELD GUIDE TO THE BIRDS OF AUSTRALIA*. Collins, Sydney.

ROBINSON, A., 1949: The biological significance of bird song in Australia. *Emu* 48: 291–315.

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BREEDING BIOLOGY AND BEHAVIOUR OF THE YELLOW-THROATED HONEYEATER, *LICHENOSTOMUS FLAVICOLLIS*

by Penelope J. Bruce

(with three tables and one text-figure)

BRUCE, P.J., 1988 (31:x): Breeding biology and behaviour of the yellow-throated honeyeater, *Lichenostomus flavicollis*. *Pap. Proc. R. Soc. Tasm.* 122(2):139–143. ISSN 0080–4703. Zoology Department, University of Queensland, St Lucia, Queensland, Australia 4067; formerly Department of Zoology, University of Tasmania.

The breeding biology and behaviour of the yellow-throated honeyeater *Lichenostomus flavicollis* was studied at Mount Nelson, Tasmania. An influx of yellow-throated honeyeaters, including females, in late June resulted in an increase in territorial disputes and the initiation of breeding activities. Nest building and incubation was only carried out by the female, while the male was occupied in territorial defence. Fledglings were fed by both parents until the female started building the next nest.

Key Words: Tasmania, yellow-throated honeyeater, breeding, biology, behaviour.

INTRODUCTION

The yellow-throated honeyeater has a nest routine largely similar to its mainland relative, the white-eared honeyeater *Lichenostomus leucotis* (Sharland 1981). Littler (1903), Dove (1917), Pizzey (1980), Sharland (1981) and Milledge (pers. comm.) concluded that the clutch size is usually two or three, the eggs being a pale buff pink and spotted with red-brown; the nest is a deep bark cup woven with grasses and lined with fur, wool or feathers and is placed within 1 m of the ground in grass tussocks or low bush.

This paper describes the breeding biology and behaviour of the yellow-throated honeyeater as observed at Mount Nelson in 1984 and during subsequent visits. All vocalisations referred to in this paper are described in Bruce (this volume).

METHODS

At the University Reserve on Mount Nelson, Hobart, two colour-banded birds belonging to different pairs were observed from February to October 1984. In one pair the male, R-Y, was banded and in the other the female, O-O, was banded. Observations took place almost every day during the breeding season.

RESULTS

Territorial Defence

At Mount Nelson, an influx of yellow-throated honeyeaters occurred in the first half of June. This was associated with an increase in territorial disputes and chasing between intruders and residents. If the intruder was perched inside a territory, the resident would land alongside it and a physical confrontation with the interaction call would result. Chasing was usually accompanied by bill snapping. Females were often seen joining the male in the chase. Once the intruder was expelled, the male returned to patrolling the territory by moving from post to post singing or aggressive calling. The female also used the aggressive call and chased intruders, but was not as vigorous as the male, who would often take over from the female after she had chased the intruder a short distance.

Courtship

Courtship was predominantly shown by driving behaviour. The male would fly towards, and dislodge, the perching female. Both pairs behaved in this way before building took place and it was also seen in the R-Y pair just before the first brood left the nest.

Nest Building

Only the female collected nest material and built the nest. Nesting material consisted of shreds of bark, dry grass and cobwebs. The bark and dry grass were woven together and held in place by spiders' web to form a small cup shape. Pieces of frayed bark were then placed in the centre and flattened with the feet.

Nest lining included treefern fibres and mammalian hair. The female would commonly perch on the back of a dog or on a human head and, with a piece of hair in her bill, would either attempt to fly off or anchor herself and pull on the hair. While she was nest building, O-O attempted to collect hair from the author's head several times a day. Her mate only landed on the author's head once and did not attempt to collect hair.

In both pairs the second nest was presumably lined with some material out of the first, as this was roughly pulled out when the new nest reached the latter stages of building.

Nest building took an average of five days, with the female attending the structure with more material at least every ten minutes. Table 1 gives more details on size and height of the nest and the vegetation in which it was placed. Note that the height of the nest above ground increased in successive broods. A nest was discovered at Mount Nelson on 15 December 1986 at a height of 18 m in a *Casuarina* tree.

Laying and Incubation

Eggs were found in the nests between 4 and 14 days after building was complete. Clutch size was two to three and one egg was laid per day between sunset and 8.30 a.m.

Incubation was carried out by the female who only left the nest to feed. When I approached the nest the female would sit on a prominent branch within 1 or 2 m of me with the posture shown in figure 1. Sometimes the bill was open during this display but no call was uttered. During incubation the male remained around the nest area, leaving only to defend the territory against intruders. Incubation time was between 16 and 17 days.

FIG. 1 — Posture adopted by the female at the nest site.

Care of Nestlings

Table 2 shows details of nestling development. Only the female feeds the nestlings. Gaping was elicited by vibration of the nest, the female's call at the nest, and also occasionally the male's song.

At about 10 days of age, the nestlings' eyes were open and they no longer responded by gaping to vibration of the nest. When the nest was vibrated by moving the bushes around it, the nestlings would open their eyes and upon seeing the author, would close their eyes again and lie flat in the nest.

Feeding frequency by the female was initially once every three to five minutes. Food included adult winged insects, insect larvae of the families Geometridae and Anthelidae and manna. Feeding frequency decreased after 14 days to an average of once every seven minutes, although the female visited the nest at the previous frequency. The nestlings left the nest the day after feeding frequency decreased.

Each time the female brought food, she checked the nest for faecal sacs, or waited to remove them as they were expelled by the nestlings. Before the young were 12 days old, the female took the faecal sacs from the nest and consumed them. However, after this age, she consumed a decreasing amount of the faecal sacs and finally all the faecal sacs were deposited on nearby tree branches. The female bill-wiped after she had collected the faecal sacs.

The male's role during this time was defence of the territory and the nestlings. The male performed the nest distraction display from eight days after the nestlings hatched. The female would also defend the nest by swooping on the author from nearby branches.

Care of Fledglings

The fledglings left the nest 16 days after hatching. They remained together in the undergrowth and were fed by both parents until the female started to build the second nest. From that time only the male fed the fledglings. The fledglings' behaviour likewise changed; only the

TABLE 1
Descriptions of Yellow-Throated Honeyeater Nests

Nest	Breeding pair			
	O-O		R-Y	
	Brood 1	Brood 2	Brood 1	Brood 2
Distance above ground of top of nest (m)	0.46	0.60	0.27	0.51
Depthof nest (mm)	70	65	70	80
External diameter (mm)	100	100	100	90
Internal diameter (mm)	70	75	70	65
Distance from first nest (m)		10		22
Vegetation supporting the nest	*Bedfordia linearis*	*Eucalyptus pulchella* (coppice)	*Lomandra longifolia*	*Goodenia ovata* in *Bursaria spinosa*

TABLE 2
Chronology of Breeding of Two Pairs at Mount Nelson

Pair	Date 1984	Observations
O-O	11 Sep	First nest found — 2 nestlings fully feathered
	13 Sep	Nestlings fledged
	19 Sep	O-O collecting cobwebs, dry grass. Male feeding fledglings
	21 Sep	Second nest almost complete
	26 Sep	1 egg
	27 Sep	2 eggs
	28 Sep	3 eggs
	7 Oct	Eggs not yet hatched
	18 Oct	3 nestlings dead (cold snap in weather)
R-Y	11 Jun	Female first seen in territory
	10 Jul	Female collecting nesting material
	17 Jul	Nest completed
	1 Aug (± 1 day)	2 eggs
	16 Aug (± 1 day)	2 nestlings: naked, eyes closed
	18 Aug	Nestlings with some down feathers, eyes closed
	22 Aug	Nestlings covered with down feathers, primary and secondary wing feathers in pin wax sheath, eyes open
	24 Aug	As above
	26 Aug	Wing feathers one-third out of sheath, contour feathers on body fully formed. Feathers covered with pieces of wax, nestlings often preen
	28 Aug	Wing feathers one-third to one-half out of sheath
	24-29 Aug	Nest distraction display by the male
	30 Aug	Wing feathers fully formed, feeding frequency decreased
	31 Aug	Nestlings fledge
	5 Sep	Second nest complete
	9 Sep	2 eggs
	10 Sep	3 eggs
	26 Sep	Eggs hatched, 3 nestlings
	5 Oct	Nestlings disappeared

"cheep" call was used for begging to the male and the fledglings became more independent of each other, except at roosting.

Flight of the fledglings commenced with short low-level jumps of about half a metre. These jumps were extended to 10 m within six days, and by three weeks after fledging the young were flying in the tops of eucalypts, following and being followed by the male. Survivorship of different stages in the development of the young of the two pairs is shown in table 3.

Multiple Broods

Both pairs had two broods up until the middle of October. The second nest was commenced between five and eight days of the young fledging. As nestlings and fledglings were found in the Hobart area in mid-December 1985 and 1986, and fledglings in early February 1984, it is probable that the two Mount Nelson pairs produced more than two broods in 1984. Green & Mollison (1961) reported that the male drives out successive broods, and finally the female, from his territory.

A chronology of the breeding activities of the two pairs observed is summarised in table 2.

DISCUSSION

It has been claimed that both the male and female yellow-throated honeyeater build the nest and incubate the eggs (Anon. 1976). However, both Milledge (pers. comm.) and the author agree that only the female carries out these activities.

Blakers *et al.* (1984) referred to Fletcher (1911) who stated that yellow-throated honeyeater nests were sometimes found within a few yards of one another. Although this statement implies that different pairs nest close to one another, this was not the case in the strictly territorial pairs at Mount Nelson. The nests that Fletcher referred to were probably nests of successive broods of one pair within a territory.

The yellow-throated honeyeater is renowned for having a very early breeding season, starting in July. This early start may reflect the abundance of food for the young. About half the nestlings' food in August was insect larvae from the families Geometridae or Anthelidae. Madden & Bashford (1977) found that *Chlenias* sp., a geometrid moth, was high in larval abundance between July and December. The production by the yellow-throated honeyeater of several small broods during the breeding season allows for an extended use of this resource.

TABLE 3
Survivorship of nestlings and fledglings from 11/6/84 to 18/10/84

Offspring	Breeding Pair			
	O-O		R-Y	
	Brood 1	Brood 2	Brood 1	Brood 2
Clutch size	-	3	2	3
Number surviving — incubation	-	3	2	3
— nestlings	2	0	2	0
— fledglings	1	0	2	0

ACKNOWLEDGEMENTS

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REFERENCES

ANON., 1976: *COMPLETE BOOK OF AUSTRALIAN BIRDS*. Readers' Digest, Sydney.

BLAKERS, M., DAVIES, S.J.J.F. & REILLY, P.N., 1984: *THE ATLAS OF AUSTRALIAN BIRDS*. Melbourne University Press, Melbourne.

BRUCE, P.J., 1988: The vocal repertoire of the yellow-throated honeyeater, *Lichenostomus flavicollis*. *Pap. Proc. R. Soc. Tasm.* 122(2): 139–142.

DOVE, H.S., 1917: Nesting of the yellow-throated honeyeater (*Ptilotis flavigula*) in northern Tasmania. *Emu* 17: 53–55.

FLETCHER, J.A., 1911: Honey-eaters of the Cleveland district, Tasmania. *Emu* 11: 105–109.

GREEN, R.H. & MOLLISON, B.C., 1961: Birds of Port Davey and south coast of Tasmania. *Emu* 61: 223–236.

LITTLER, F.M., 1903: Notes on some birds peculiar to Tasmania. *Emu* 3: 81–89.

MADDEN, J.L. & BASHFORD, R., 1977: The life history and behaviour of *Chlenias* sp., a geometrid defoliator of *Radiata* pine in Tasmania. *J. Aust. Ent. Soc.* 16: 371–378.

PIZZEY, G., 1980: *A FIELD GUIDE TO THE BIRDS OF AUSTRALIA*. Collins, Sydney.

SHARLAND, M., 1981: *A GUIDE TO THE BIRDS OF TASMANIA*. Drinkwater Publishing, Hobart.

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TASMANIAN HIGH MOUNTAIN VEGETATION III — LAKE EWART, DOME HILL AND ELDON BLUFF

by J. B. Kirkpatrick and Jennifer Whinam

(with three tables, six text-figures and three plates)

KIRKPATRICK, J.B. & WHINAM, J., 1988 (31:x): Tasmanian high mountain vegetation III — Lake Ewart, Dome Hill and Eldon Bluff. *Pap. Proc. R. Soc. Tasm.* 122(2): 145–164. ISSN 0080–4703. Department of Geography, University of Tasmania, G.P.O. Box 252C, Hobart, Tasmania 7001

The Lake Ewart region is highly varied geologically and topographically. It lies within a biologically poorly known and remote part of Tasmania. Eldon Bluff, a high dolerite plateau, is largely covered by mosaic bolster heath within which have formed shallow peat ponds similar to those at Newdegate Pass. Dome Hill, topped by fissile mudstones, has stone stripes similar to those recorded for the fjaeldmarks of Pyramid Hill. Subalpine scrub and forest is largely dominated by *Eucalyptus coccifera* and *E. subcrenulata*, although *E. nitida* is important on quartzite. There are small areas of *Athrotaxis* cupressoides woodland and rainforest dominated by *Nothofagus cunninghamii*. The treeless subalpine vegetation consists of a mixture of short herbfield, *Sphagnum* bog and tussock sedgeland on the more fertile substrates, while heathy sedgeland and scrub predominate on more siliceous soils.

Key Words: Lake Ewart, Eldon Bluff, Dome Hill, peat, subalpine vegetation.

INTRODUCTION

The general patterns of variation in the high mountain treeless vegetation of Tasmania are now moderately well understood (Kirkpatrick 1982, 1983, 1986a, 1986b). Earlier papers in this series (Kirkpatrick 1980, 1984) and other work (Martin 1940, Davies 1978, Kirkpatrick & Harwood 1980, Noble 1981, Minchin 1985, Wells 1985) have provided detailed accounts of high mountain vegetation and its environmental relationships for particular mountains. These "windows" supplement the more general ecological studies. The area containing Lake Ewart, Dome Hill and Eldon Bluff was selected for detailed study because of its environmental, particularly geological, diversity within a remote, biologically unknown region where rainfall almost certainly exceeds 2000 mm (fig. 1).

METHODS

All higher plant species observed were noted and/or collected during a field trip in February 1987. Nomenclature follows Curtis (1963, 1967, 1979), Curtis & Morris (1975), Curtis & Stones (1978) and Willis (1970) with the latest publication having precedence. Authors are given wherever nomenclature does not follow these authorities. Specimens are held in the Herbarium of the Tasmanian Museum and Art Gallery.

Notes were made of the occurrence and environmental relationships of species, vegetation structure and periglacial landforms. Sixty-one 10 x 10 m quadrats were located in order to encompass the major part of the variation in the vegetation. All higher plant species, the dominant species, the vegetation structure and details of the environment of each quadrat were recorded. Transects consisting of 2 x 2 m quadrats were placed to typify the phytosociological and environmental situations of two *Sphagnum* bogs (fig. 1A). The longer transect consisted of quadrats separated by 10 m, while in the shorter one the quadrats were contiguous. Peat depths were measured with a metal rod and the surface topography mapped with a clinometer. The vegetation was mapped from field observation and interpretation of 1979 panchromatic vertical aerial photographs.

The 10 x 10 m quadrat floristic data were classified using the polythetic divisive strategy in the program TWINSPAN (Hill 1979). The species in the table produced by TWINSPAN were reorganised using ORDTAB in the ECOPAK suite of programs (Minchin 1986) in order that species with similar distribution patterns could be as close to each other as possible. The results of this procedure cannot be distinguished from those of the hand-sorting method used and justified in earlier papers in this series. Eight groups of quadrats were selected from the results of the

FIG. 1 — (A) Location of study area, location of quadrats (numbered 1 to 61) and transects within the study area. (B) The locations of the mountains: 1—Ironstone Range, 2—Southern Range, 3—Eastern Arthurs, 4—Mt Bobs/Boomerang, 5—Adamsons Peak, 6 — Hartz Mts, 7 — Mt Picton, 8 — Mt Anne, 9 — Denison Range, 10 — Frenchmans Cap, 11 — Mt Sedgwick, 12 — Tyndall Range, 13 — Mt Road, 14 — Mt Murchison, 15 — Black Bluff, 16 — Mt Roland, 16.5 — Pyramid Mt/Rocky Hill, 17 — Cradle Mt/Barn Bluff, 18 — Mt Oakleigh, 19 — Mt Ossa/Pelion East, 20 — Walled Mt, 21 —Mt Rufus, 22 — Mt King William I, 23 — Mt Field, 24 — Mt Wellington, 25 — Ben Lomond, 26 — Mt Barrow, 27 — Table Mt, 28 — Central Plateau.

FIG. 2 — The similarities of the floras of other Tasmanian mountains to those of Dome Hill (D) and Eldon Bluff (E). Locations and numerical codes of the mountains are shown in figure 1.

TWINSPAN analysis. These groups are called communities in the rest of the paper and are named by their two or three most characteristic species, that is, the species with maximum fidelity and high constancy. Structural terminology follows Kirkpatrick (1983) for the alpine subformations, Gibson & Kirkpatrick (1985) for the divisions of bolster heath, Kirkpatrick & Harwood (1983) for wetland communities, and Specht (1972) for other vegetation.

RESULTS AND DISCUSSION

Floristic Relationships of Alpine Floras

Both mountains belong to the central Tasmanian (group 3) floras of Kirkpatrick (1982). Despite their close proximity, Dome Hill and Eldon Bluff have closer floral affinities to other mountains than to each other (fig. 2), reflecting substrate, topographic and altitudinal differences, most notably the higher altitude and poorer drainage of the high plateau on Eldon Bluff compared to the rounded peak of Dome Hill. Dome Hill has its highest floristic affinity with the nearby sedimentary peak of Pyramid Mountain, while the flora of Eldon Bluff most resembles those of Cradle Mountain and Mt Field (fig. 2).

Alpine Plant Communities (TWINSPAN groups 1 and 2)

The quadrats in alpine vegetation were placed into two distinct groups (table 1 (pp.154–155), fig. 3). The *Donatia novae-zelandiae – Dracophyllum minimum – Carpha rodwayi* community consists of mosaic bolster heath on the high plateau of Eldon Bluff. Within the mosaic bolster heath there is variation from dominance by *Carpha rodwayi* and *Donatia novae-zelandiae* in the most waterlogged areas to dominance by *Dracophyllum minimum*, *Pterygopappus lawrencei* and *Donatia novae-zelandiae* in areas where drainage appears to be better. Better drainage is also associated with greater peat depth on the dolerite pediment (plate 1A,B). Organic dams and flark ponds, are floristically similar to those found at Newdegate Pass (Kirkpatrick & Gibson 1984), and although less well-developed are frequent in the mosaic bolster heath (plates 1C,D).

The *Orites revoluta–Senecio pectinatus–Poa gunnii* community (table 1) consists of quadrats in tall alpine herbfield, short alpine herbfield, heath, coniferous heath and fjaeldmark, all on better drained sites than the quadrats in the other alpine community. This structurally heterogeneous group was further divided by the TWINSPAN analysis into:

(1) two quadrats on the steep slopes beneath the cliffs and blockstreams of Eldon Bluff, one (31)

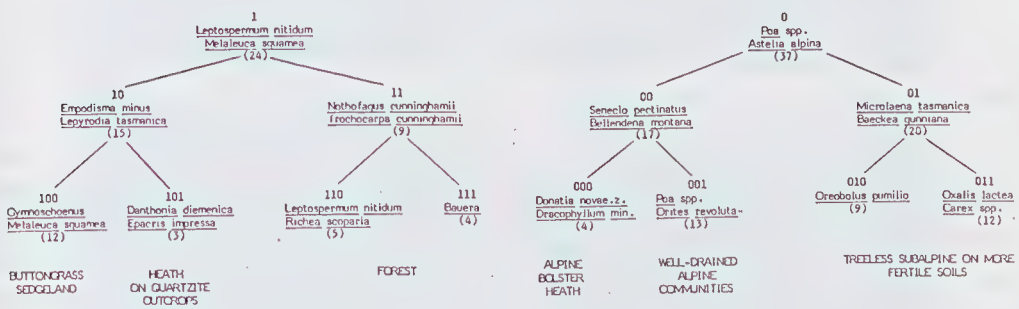

FIG. 3 — Group and subgroup structure of TWINSPAN analyses.

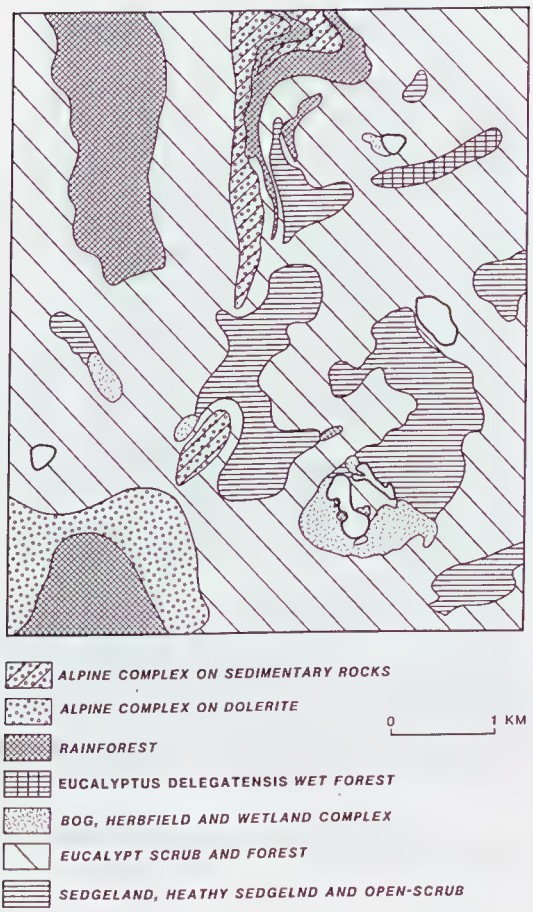

FIG. 4 — Vegetation map of the study area.

being heath on a rocky scree, the other (32) being *Milligania densiflora* tall alpine herbfield on a convex fan receiving considerable drainage;
(2) a singleton group consisting of quadrat 33 which was situated in an *Astelia alpine–Milligania densiflora* tall alpine herbfield in a snow accumulation site on the eastern slopes of the sedimentary plateau below Eldon Bluff;
(3) a group of four quadrats (26, 28, 38, 40) which includes two well-drained sites on the high plateau of Eldon Peak, and two sites, one in fjaeldmark, on the steepest parts of Dome Hill;
(4) a group of six quadrats in heath, short alpine herbfield and fjaeldmark (plate 1D) on the gentler slopes of Dome Hill.

Fjaeldmark is concentrated on the steep west and southwest facing slopes on mudstone and the flat tops of sandstone plateaus (plate 1D). The fjaeldmark on the steep mudstone slopes of Dome Hill is identical in its characteristics to that described for Pyramid Mountain (Kirkpatrick 1984). The type of fjaeldmark illustrated in plate 1D appears to owe its genesis to disturbance by fire reinforced by repeated inundation, drying and frost disturbance (Kirkpatrick 1984). This subformation may be an ephemeral feature as it is not found in sites of similar altitude, exposure and substrate.

Tall alpine herbfield dominated by *Milligania densiflora* occupies much of the cliff base of Eldon Bluff (plate 2A), being concentrated in persistent flushes where sediment accumulates. Short alpine herbfield occurs where wind-deposited fine sediments accumulate on the drier lee slope of Dome Hill. However, most of the alpine zone is occupied by heath in which dominance is highly variable both between and within sites. Some coniferous heath is found on both mountains, indicating that parts of their peaks have not been fired for a considerable number of years (Kirkpatrick & Dickinson 1984). There is, however, evidence of at least one fire that occurred more than 30 years ago (estimate from *Banksia* whorl count) over most of the study area, and through much of the alpine zone, particularly on Dome Hill.

Treeless Subalpine Plant Communities (TWINSPAN Groups 3 and 4)

Two TWINSPAN groups are discriminated within this general grouping (fig. 3). They are the *Restio australis–Oreobolus pumilio* community which is found on the more poorly-drained sites in this category, and the *Carex* aff. *apressa–Oxalis lactea–Lagenophora stipitata* community, the quadrats of which occur at least partly on better drained ground with soils composed of peat, silt and boulder clay (table 2, pp.156–157). The latter community has most of the same species as the former, but is richer in small herbs such as *Diplaspis cordifolia*, *Herpolirion novae-zelandiae* and *Hydrocotyle sibthorpioides*, a probable product of the interaction between relatively fertile soils and considerable grazing pressure from wombats and wallabies. This interaction forms scat-laden marsupial lawns (plate 2B) which are concentrated where silt is deposited from normally subterranean streams in the flats to the west and southwest of Lake Ewart (fig. 4).

Sphagnum cristatum bogs transgress both communities. The usual dominant in the bogs is *Richea gunnii*, a species that elsewhere is largely associated with *Sphagnum cristatum* (table 2).

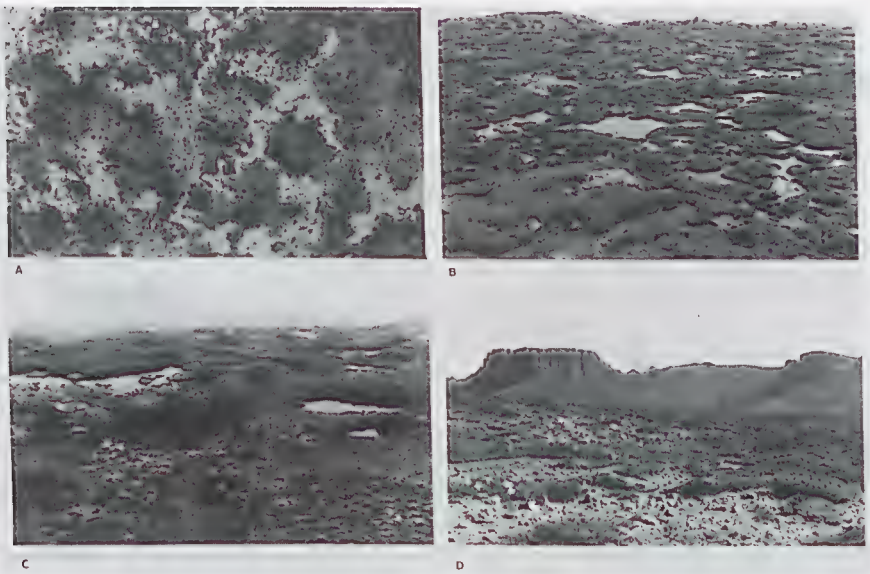

PLATE 1

(A) Mosaic cushion heath from above with Carpha alpina *emerging from (light to dark)* Pterygopappus lawrencei, Donatia novae-zelandiae *and* Dracophyllum minimum; *(B) The plateau on Eldon Bluff.* Carpha rodwayi *is dominant in the foreground where it is initiating the formation of small pools; (C) Mosaic cushion heath and peat-dammed ponds on the Eldon Bluff plateau; (D) Fjaeldmark on the sandstone of Dome Hill with Eldon Bluff in the background.*

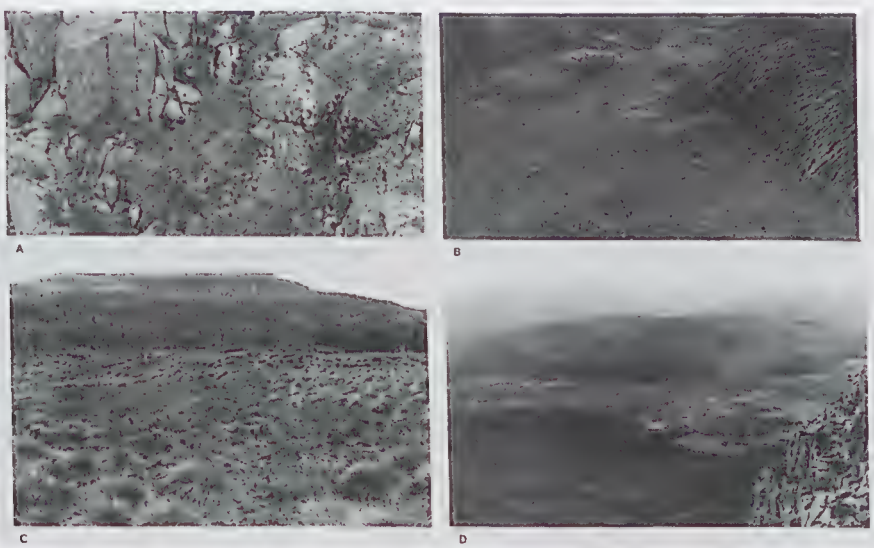

PLATE 2

(A) Milligania densiflora *tall alpine herbfield on the northern face of Eldon Bluff; (B) Marsupial lawn between Gymnoschoenus* sphaerocephalus *hummocks; (C) The plain to the east of Lake Ewart looking towards Castle Mountain.* Gymnoschoenus sphaerocephalus *tussock sedgeland occupies the moraine ridges.* Sphagnum *bog dominated by* Richea gunnii *occupies the flats.* Eucalyptus subcrenulata–E. coccifera *forest occupies the background; (D) Lake Ewart and the quartzite ridges from Eldon Bluff.*

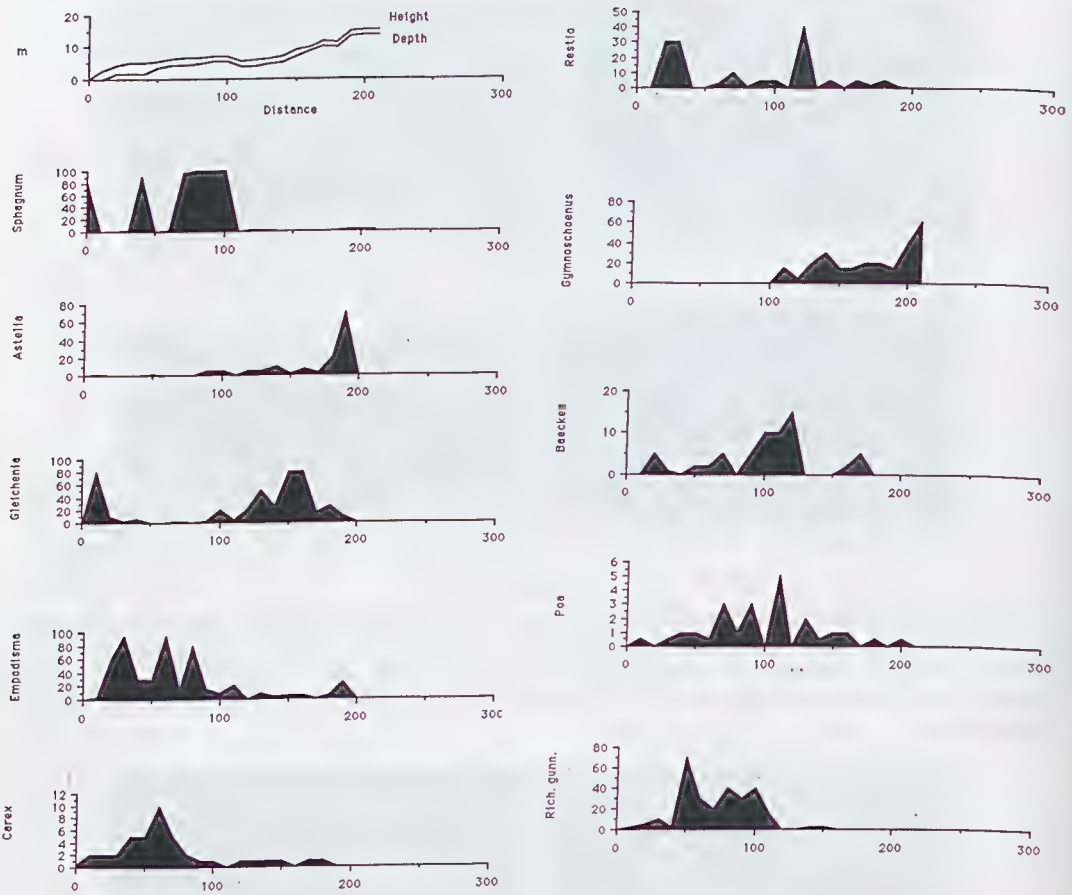

FIG. 5 — Transect across a Sphagnum *bog to the west of Lake Ewart (fig. 1) showing surface topography, peat depth and variation in the cover of the more important species.*

However, the abundances of *S. cristatum* and *R. gunnii* are often inversely related at the transect scale (figs 5, 6). Two metres of peat have accumulated between the moraines (figs 5, 6; plate 2C), possibly not all attributable to *Sphagnum* and its associates, as *Carex gaudichaudiana* dominates some small areas of shallow wetland within the matrix of the *Sphagnum*. In some places *Sphagnum* is intermixed with tussocks of *Gymnoschoenus sphaerocephalus*, a relatively unusual association (Whinam, unpublished data). Also unusual is the presence of *S. cristatum* as a dominant in the ground stratum of scrub dominated by *Leptospermum rupestre* and forest dominated by *Eucalyptus subcrenulata*. The Lake Ewart region also contains an ombrotrophic (raised) *Sphagnum* bog, a rare phenomenon in Tasmania.

Treeless Vegetation Complex on Highly Siliceous Rocks

To the east of Lake Ewart glacial activity has left an erosional surface consisting of quartzite *roche moutonnee* steps which run as north-west–southeast ridges, occasionally breached by major streams. Quadrats from the quartzite catena which runs from skeletal ridge to peaty and poorly-drained valley are included within the *Gymnoschoenus sphaerocephalus–Melaleuca squamea–Empodisma minus* community and the *Epacris impressa–Danthonia diemenica* community (table 3, pp.158–159). Soil (= peat) depth and drainage interact such that the poorly drained and constantly wet valleys support *Gymnoschoenus sphaerocephalus* tussock sedgeland or heathy

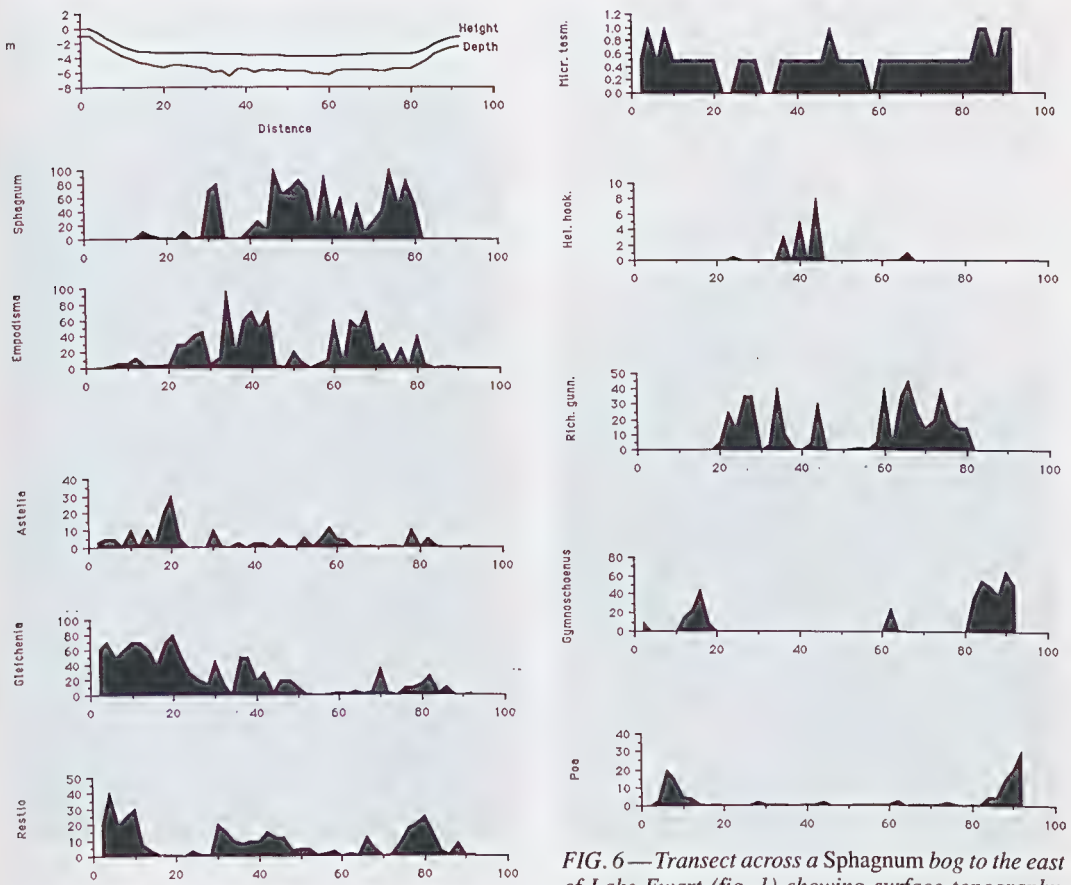

FIG. 6 — Transect across a Sphagnum *bog to the east of Lake Ewart (fig. 1) showing surface topography, peat depth and variation in the cover of the more important species.*

sedgeland (*sensu* Kirkpatrick 1977) dominated by *Melaleuca squamea*. The better-drained areas with some soil have a scatter of 4-6 m tall *Banksia marginata* with less than 10% cover overlaying a mixture of myrtaceous shrubs and sedges. The ridges have little vegetation cover, what there is being concentrated in crevices and cracks. They do, however, have a distinct floristic composition (table 3, pp.158–159).

Forest Communities (TWINSPAN Groups 5 and 6)

Open-forest dominated by *Eucalyptus coccifera* and/or *E. subcrenulata* (plate 3A), or rainforest (*sensu* Jarman & Brown 1983), are found below 1100 m on dolerite, sedimentary rocks and deposits ultimately derived from these sources, where drainage is good or fire highly infrequent. The two forest communities discriminated by TWINSPAN (table 3, fig. 3) transgress the open-forest/rainforest boundary. The *Richea scoparia–Phyllocladus aspleniifolius* community is successionally closer to the open communities than is the *Eucalyptus subcrenulata–Oxalis lactea* community. However, there are few lowland parts of the study area that do not show evidence of succession from open vegetation to rainforest, so lucidly posited to follow fire by Jackson (1968), Bowman & Jackson (1981) and Brown & Podger (1982). One such stand of pure rainforest is protected by the fjaeldmark arc of Dome Hill. Another is protected by a sandstone cliff (fig. 4). Three small patches of *Athrotaxis cupressoides* woodland, one on a poorly-drained site, have been protected from fire by the morphology of Lake

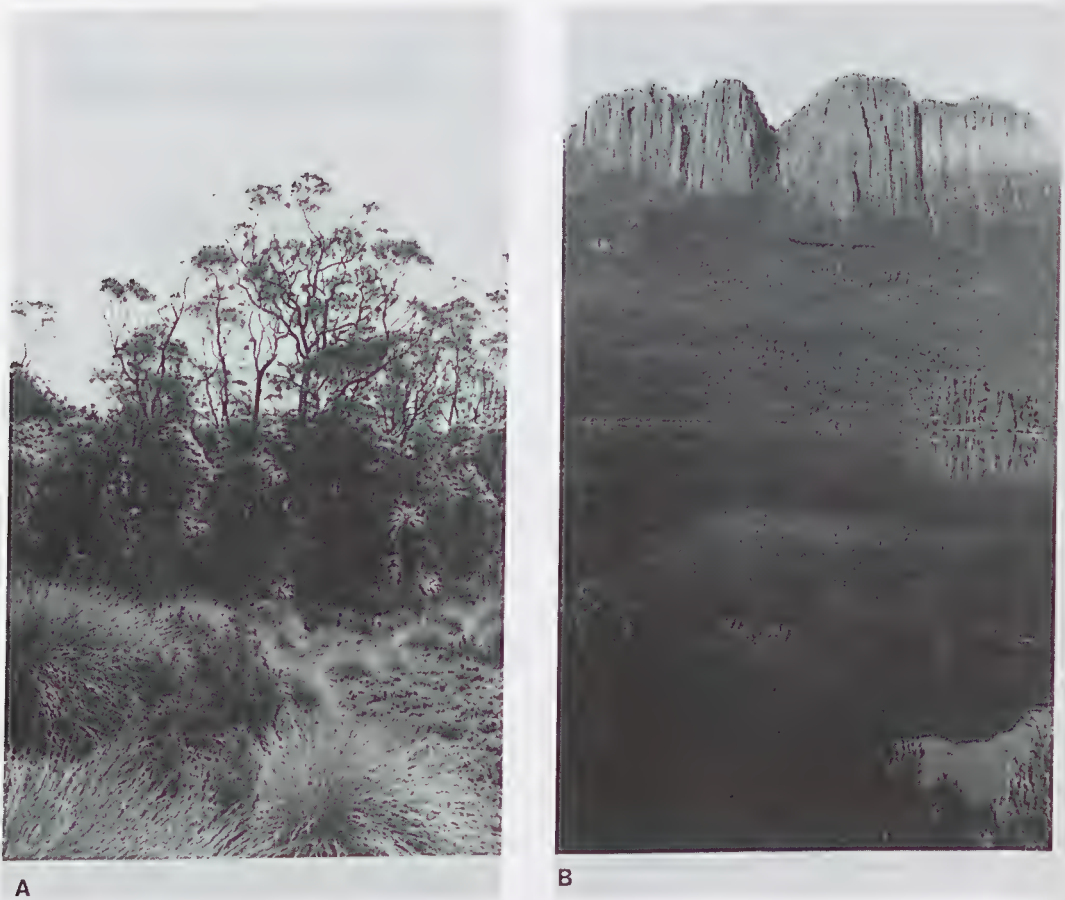

PLATE 3

(A) Eucalyptus subcrenulata *open-forest over a* Nothofagus cunninghamii *rainforest understorey with* Gymnoschoenus sphaerocephalus, Baeckea gunniana *and a sward of* Gleichenia alpina *in the foreground; (B) Lake Ewart and Eldon Bluff with* Eleocharis acuta *aquatic sedgeland in the foreground and a small stand of* Athrotaxis cupressoides *woodland in the right middleground on a fire-protected peninsula. The lower slopes of Eldon Bluff are covered by* E. coccifera *open-forest burned more than 30 years ago.*

Ewart (fig. 4). The woodland on the poorly drained site (15) was classified with the *Carex* aff. *appressa–Richea gunnii–Lagenophora stipitata* community rather than either of the forest communities.

The *Eucalyptus coccifera* low open-forest which covers steep sedimentary and dolerite slopes between 900 m and the upper treeline (plate 3B) has an understorey that varies from dwarfed rainforest species, particularly myrtle, to sedges and sclerophyll shrubs, particularly *Gahnia grandis* and *Orites revoluta*. No *Eucalyptus delegatensis* stand was visited, although some forest of this type was mapped (fig. 4) from its distinct crown attributes. *Eucalyptus nitida* and its intermediates with *E. coccifera* form an occasional patch of low open-forest in quartzite valleys.

Wetland Vegetation

Lake Ewart is a shallow (mostly less than 2 m), mesotrophic water body with a floor largely covered by organic ooze. The deeper parts of the lake support an aquatic herbfield dominated by

Isoetes gunnii. Near the eastern and southeastern shores is good development of *Myriophyllum* aquatic herbfield and occasional patches of *Eleocharis acuta* sedgeland (plate 3B) and *Carex gaudichaudiana* sedgeland. Rich marginal herbfields have developed on the gentler shores. These are highly variable in their species composition and appear to be heavily grazed by marsupials.

In ponds and small lakes that have formed in the more siliceous country *Baumea arthrophylla* sedgeland, *Agrostis meionectes* grassland and *Myriophyllum pedunculatum* marginal herbfield were observed.

GENERAL DISCUSSION

The patterns of variation in vegetation of the study area largely conform to previous correlations that have been made between vegetation type and environment in perhumid Tasmania. Alpine vegetation (*sensu* Kirkpatrick 1983) is found above the climatic treeline and on sites below the climatic treeline where poor drainage or exposure inhibit growth of most lowland species and subalpine trees. Thus, the alpine element is most prominent at the lowest altitudes in the study area on the southeast-facing cliffs, on skeletal soils on ridges and on badly waterlogged ground. Within the alpine zone there is clear variation related to soil qualities, drainage and the decline in summer warmth with altitude. The terrestrial vegetation at lower altitudes fits well within the models provided by Jackson (1968) and Kirkpatrick & Duncan (1987), and the wetland vegetation fits within the model provided by Kirkpatrick & Harwood (1983). The role of substrate in mediating vegetation type is critical within all these models.

The Lake Ewart region straddles the boundary between the siliceous country of western Tasmania and the more argillaceous country of the centre of Tasmania, the Eldon Range forming a salient of fertility in a high rainfall and oligotrophic landscape. Thus, it is not surprising that its bogs and alpine vegetation have attributes and species that are rare in Tasmania as a whole. It is fortunate that some of the area is reserved and desirable that the rest of it gains the same status.

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REFERENCES

BOWMAN, D.M.J.S. & JACKSON, W.D., 1981: Vegetation succession in southwest Tasmania. *Search* 12: 358–362.

BROWN, M.J. & PODGER, F.D., 1982: Floristics and fire regimes of a vegetation sequence from sedgeland-heath to rainforest at Bathurst Harbour, Tasmania. *Aust. J. Bot.* 30: 659–676.

CURTIS, W.M., 1963: *THE STUDENT'S FLORA OF TASMANIA, PART II*. Government Printer, Tasmania.

CURTIS, W.M., 1967: *THE STUDENT'S FLORA OF TASMANIA, PART III*. Government Printer, Tasmania.

CURTIS, W.M., 1979: *THE STUDENT'S FLORA OF TASMANIA, PART IVA*. Government Printer, Tasmania.

CURTIS, W.M. & MORRIS, D.I., 1975: *THE STUDENT'S FLORA OF TASMANIA, PART 1*. Second edition, Government Printer, Tasmania.

CURTIS, W.M. & STONES, M., 1978: *THE ENDEMIC FLORA OF TASMANIA, VOLUME VI*. Ariel Press, London.

DAVIES, J.B., 1978: Alpine and subalpine communities of the Mt Field National Park and Mt Rufus. Unpubl. B.Sc. Hons. thesis Univ. Tasm.

GIBSON, N. & KIRKPATRICK, J.B., 1985: A comparison of the cushion plant communities of New Zealand and Tasmania. N.Z. J. Bot. 23: 549–566.

HILL, M.O., 1979: *TWINSPAN*. Cornell Univ., Ithaca.

JACKSON, W.D., 1968: Fire, air, water and earth — an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* 3: 9–16.

JARMAN, S.J. & BROWN, M.J., 1983: A definition of cool temperate rainforest in Tasmania. *Search* 14: 81–87.

KIRKPATRICK, J.B., 1977: Vegetation of the West Coast region. *In* Banks M.R. & Kirkpatrick J.B. (Eds): *LANDSCAPE AND MAN*. Royal Society of Tasmania, Hobart: 55–80.

KIRKPATRICK, J.B., 1980: Tasmanian high mountain vegetation I — A reconnaissance survey of the Eastern Arthur Range and Mount Picton. *Pap. Proc. R. Soc. Tasm.* 114: 1–20.

KIRKPATRICK, J.B., 1982: Phytogeographical analysis of Tasmanian alpine floras. *J. Biogeogr.* 9: 255–271.

KIRKPATRICK, J.B., 1983: Treeless plant communities of the Tasmanian high country. *Proc. Ecol. Soc. Aust.* 12: 61–77.

KIRKPATRICK, J.B., 1984: Tasmanian high mountain vegetation II — Rocky Hill and Pyramid Mountain. *Pap. Proc. R. Soc. Tasm.* 118: 5–20.

KIRKPATRICK, J.B., 1986a: Conservation of plant species, alliances and associations of the treeless high country of Tasmania, Australia. *Biol. Conserv.* 37: 43–57.

KIRKPATRICK, J.B., 1986b: Tasmanian alpine biogeography and ecology and interpretations of the past. *In* Barlow B.A. (Ed.): *FAUNA AND FLORA OF ALPINE AUSTRALASIA*. C.S.I.R.O., Melbourne: 229–242.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984: The impact of fire on Tasmanian alpine vegetation and soils. *Aust. J. Bot,* 32: 613–629.

KIRKPATRICK, J.B. & DUNCAN, F., 1987: Tasmanian high altitude grassy vegetation: its distribution, community composition and conservation status. *Aust. J. Ecol.* 12: 73–86.

KIRKPATRICK, J.B. & GIBSON, N., 1984: Dynamics of a Tasmanian bolster heath string fen. *Vegetatio* 47: 71–78.

KIRKPATRICK, J.B. & HARWOOD, C.E., 1980: Vegetation of an infrequently burned Tasmanian mountain region. *Proc. R. Soc. Vict.* 91: 79–107.

KIRKPATRICK, J.B. & HARWOOD, C.E., 1983: Tasmanian wetland plant communities. *Aust. J. Bot.* 31: 437–451.

MARTIN, D., 1940: The vegetation of Mt Wellington, Tasmania — the plant communities and a census of the plants. *Pap. Proc. R. Soc. Tasm.* (1939): 97–124.

MINCHIN, P.R., 1985: A comparative evaluation of techniques for ecological ordination using simulated vegetation data and an integrated ordination-classification analysis of the alpine and subalpine plant communities of the Mount Field Plateau, Tasmania. Unpubl. Ph.D. thesis Univ. Tasm.

MINCHIN, P.R., 1986: How to use ECOPAK: an ecological database system. CSIRO Institute of Biological Resources, Division of Water and Land Resources Technical Memoir 86/6.

NOBLE, M.G., 1981: Vegetation organization along altitudinal gradients in Tasmania. Unpubl. Ph.D. thesis, Aust. Nat. Univ.

SPECHT, R.L., 1972: THE VEGETATION OF SOUTH AUSTRALIA. Government Printer, Adelaide.

WELLS, J., 1985: A vegetation description of the Nevada Peak area of the Snowy Range. Unpubl. B.Sc. Hons. thesis Univ. Tasm.

WILLIS, J.H., 1970: A HANDBOOK TO *PLANTS IN VICTORIA, VOL. I.* Second edition, Melbourne University Press, Melbourne.

(accepted 30 March 1988)

TABLE 1
Alpine Communities

	TWINSPAN																
	000				001												
Species*	2 5	2 7	2 9	3 0	3 3	4 1	3 9	3 7	3 6	3 5	3 4	4 0	3 8	2 8	2 6	3 2	3 1
Senecio pectinatus	1	-	-	1	1	1	-	1	-	1	-	1	-	1	1	1	1
Carpha alpina	1	-	-	1	-	1	1	-	1	-	1	-	1	-	1	-	-
Cyathodes dealbata	1	1	-	-	-	1	-	1	1	1	1	-	1	-	1	-	-
Epacris serpyllifolia	1	1	-	-	-	1	1	1	1	1	-	1	1	1	1	-	-
Bellendena montana	1	1	-	1	-	-	-	1	1	1	-	1	1	1	1	1	-
Milligania densiflora	1	1	-	1	1	-	-	-	-	-	-	1	1	1	-	1	1
Euphrasia spp.	-	1	-	-	-	1	1	1	-	1	1	-	-	1	-	1	1
Gentianella diemensis	1	1	1	1	1	-	-	1	1	-	-	-	-	1	1	1	-
Oreobolus pumilio	1	1	1	1	1	1	1	1	1	-	1	-	-	-	-	-	-
Erigeron stellatus	1	1	1	-	-	-	-	-	1	-	1	-	-	-	-	-	-
Ewartia meredithae	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Dracophyllum minimum	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Donatia novae-zelandiae	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Drosera arcturi	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Carpha rodwayi	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Mitrasacme archeri	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Pterygopappus lawrencei	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Campynema lineare	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sprengelia incarnata	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Coprosma pumila	-	1	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-
Diplaspis cordifolia	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrolepis monogyna	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species*	TWINSPAN 000				TWINSPAN 001												
	25	27	29	30	33	41	39	37	36	35	34	40	38	28	26	32	31
Hibbertia procumbens	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Diplarrena latifolia	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-
Lycopodium scariosum	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-
Schoenus calyptratus	1	-	-	-	1	1	-	1	-	-	-	-	-	-	-	1	-
Danthonia pauciflora	-	1	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-
Baeckea gunniana	1	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-
Empodisma minus	1	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-
Microlaena tasmanica	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Celmisia longifolia	-	-	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-
Astelia alpina	-	1	-	-	1	-	1	1	1	1	1	-	-	-	-	-	-
Plantago tasmanica	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-
Helichrysum milliganii	-	-	-	-	-	1	1	-	1	1	1	-	-	-	-	-	-
Helichrysum backhousei	-	-	-	-	-	-	-	1	1	1	1	1	-	1	-	-	-
Exocarpos humifusus	-	-	-	-	-	-	-	1	1	1	-	1	1	-	-	-	1
Luzula spp.	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-
Microcachrys tetragona	1	-	-	-	-	-	-	-	-	1	1	-	-	-	1	-	-
Helichrysum acuminatum	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Cyathodes straminea	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	1
Olearia ledifolia	-	-	-	-	-	-	-	-	-	1	-	1	-	1	1	-	-
Richea sprengelioides	-	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	1
Senecio leptocarpus	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
Uncinia compacta	-	-	-	-	1	-	-	-	-	-	1	-	1	1	-	-	-
Nothofagus cunninghamii	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Deyeuxia monticola	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	1
Orites acicularis	1	-	-	1	-	-	-	-	-	-	-	-	-	1	1	1	-
Dichosciadeum ranunculaceum	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Diselma archeri	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Heirochloe fraseri	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Pimelea sericea	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1
Mitrasacme montana	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	1
Telopea truncata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Brachycome spathulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Drimys lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1
Coprosma nitida	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	1
Gonocarpus montanus	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	1
Rubus gunnianus	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1
Gnaphalium collinum	-	-	-	-	1	1	-	-	-	-	-	-	1	-	-	1	-
Viola hederacea	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Poa gunnii	-	-	-	1	-	1	1	1	1	1	1	1	1	1	1	1	1
Pentachondra pumila	1	-	-	-	1	1	1	1	1	1	-	-	1	-	1	-	1
Richea scoparia	-	-	-	-	1	-	-	-	1	-	1	-	1	-	-	-	1
Leptospermum rupestre	-	-	-	-	1	-	-	1	1	1	-	1	-	-	1	1	1
Lycopodium fastigiatum	-	-	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-
Orites revoluta	-	-	-	1	1	1	-	1	1	1	-	1	1	-	1	-	1
Oreobolus acutifolius	-	-	-	-	1	-	-	-	1	-	-	-	1	-	1	-	-

Additional species: 27, *Gaimardia fitzgeraldii*, *Milligania lindoniana*; 33, *Cotula alpina*, *Cyathodes petiolaris*, *Hydrocotyle sibthorpioides*, *Juncus* sp.; 41, *Agrostis parviflora*; 35, *Danthonia fortunae-hibernae*; 34, *Richea pandanifolia*; 40, *Podocarpus lawrencei*; 28, *Abrotanella scapigera*, *Archeria serpyllifolia*; 32, *Helichrysum scorpioides*; 31, *Lagenophora stipitata*, *Senecio gunnii*, *Spyridium gunnii*.

* *Species shown in bold letters are the major differentiating species.*

TABLE 2
Treeless Subalpine Communities

Species*	TWINSPAN 010									TWINSPAN 001										
	5	42	58	10	59	1	2	12	14	11	13	16	18	19	22	20	21	53	54	15
Baeckea gunniana	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1
Empodisma minus	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	-	1	-	1	-
Astelia alpina	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	1	-	1	1
Microleana tasmanica	1	-	-	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1
Rubus gunnianus	1	-	-	-	1	1	1	1	-	1	1	1	1	-	1	1	1	1	1	1
Poa gunnii	-	1	-	1	1	1	1	1	1	1	-	-	1	1	1	-	1	1	1	-
Richea gunnii	1	1	-	-	-	-	1	-	1	1	1	-	1	1	-	1	1	-	-	1
Sphagnum cristatum	1	1	-	1	-	-	1	-	1	1	1	-	-	-	-	1	1	1	-	1
Gymnoschoenus spherocephalus	-	-	-	1	1	-	-	1	-	-	1	-	-	-	-	-	1	-	1	-
Gleichenia alpina	1	1	1	-	1	1	-	1	1	1	1	1	1	1	1	-	-	-	1	-
Restio australis	1	-	-	1	-	1	1	1	1	1	1	1	-	1	-	-	-	-	-	1
Diplarrena latifolia	-	-	1	1	1	-	1	1	1	-	-	1	1	1	-	-	1	-	-	-
Melaleuca squamea	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Richea scoparia	-	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Oreobolus pumilio	1	1	1	1	1	1	-	-	-	-	-	-	-	-	1	1	-	1	-	-
Erigeron stellatus	1	1	-	1	1	1	-	-	-	-	-	1	1	-	-	-	1	1	-	-
Celmisia longifolia	1	-	-	1	1	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-
Centrolepis monogyna	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epacris serpyllifolia	-	1	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Mitrasacme montana	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera arcturi	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sprengelia incarnata	-	1	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Lepidosperma filiforme	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hibbertia procumbens	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Actinotus moorei	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentachondra pumila	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Gentianella diemensis	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Richea pandanifolia	-	-	-	1	-	-	-	-	-	1	-	-	1	1	-	-	-	-	1	-
Carex sp.	1	1	1	-	-	-	-	-	-	1	1	1	1	1	1	1	1	1	1	-
Oxalis lactea	-	-	-	1	-	-	1	-	-	1	1	-	1	1	1	1	1	1	1	1
Pultenaea subumbellata	-	-	-	-	-	1	-	-	1	-	-	1	1	-	1	-	-	-	-	-
Plantago daltoni	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	1	-	-	-
Leptospermum rupestre	-	-	-	1	-	1	-	1	-	-	-	1	1	1	1	-	1	-	-	1
Diplaspis cordifolia	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-
Helichrysum scorpioides	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	1	-
Viola hedreacea	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	1	-	-
Asperula gunnii	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-
Oreomyrrhis ciliata	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	1	-	1	1	-
Lagenophora stipitata	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1	1	1	1
Hydrocotyle sibthorpioides	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	1	-	-
Gnaphalium collinum	-	-	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	1	-	-
Herpolirion novae-zelandiae	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-
Acaena montana	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-
Lissanthe montana	-	-	-	1	-	-	-	-	-	-	-	-	1	1	-	-	-	-	1	-
Lycopodium fastigiatum	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	1	-
Acaena novae-zelandiae	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	1	-

Species*	TWINSPAN 010									001										
	5	4 2	5 8	1 0	5 9	1	2	1 2	1 4	1 1	1 3	1 6	1 8	1 9	2 2	2 0	2 1	5 3	5 4	1 5
Epilobium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
Gonocarpus micranthus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-
Scirpus aucklandicus	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-
Juncus spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Cotula alpina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-
Agrostis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-
Deyeuxia monticola	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-
Hypericum japonicum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-
Blechnum pennamarina	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1
Monotoca aff. *linifolia*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Carpha alpina	-	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Epacris lanuginosa	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Danthonia pauciflora	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Olearia erubescens	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-
Carex gaudichaudiana	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Leptospermum lanigerum	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-

Additional species: 42, *Plantago tasmanica*; 58, *Leptospermum lanigerum*; 10, *Coprosma moorei*; 59, *Lepyrodiatasmanica, Restio companatus, Stylidium graminifolium*; 1, *Tetratheca procumbens*; 12, *Gonocarpus montanus*; 15, *Athrotaxis cupressoides, Cyathodes straminea, Drimys lanceolata, Pittosporum bicolor, Trochocarpa gunnii*; 54, *Microseris scapigera*; 53, *Drosera pygmaea*; 21, *Coprosma nitida, Lycopodium laterale*; 20, *Ranunculus* sp.; 18, *Oreobolus acutifolius, Helichrysum backhousei*; 16, *Bauera rubioides, Bellendena montana*; 11, *Eucalyptus coccifera*.

* Species shown in bold letters are the major differentiating species.

TABLE 3
Quartzite and Forest Communities

Species*	TWINSPAN 101			100													110					111			
	50	47	46	44	45	43	7	6	61	49	48	17	57	4	3	23	24	8	9	60	51	25	55	56
Lomatia polymorpha	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Persoonia gunnii	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Danthonia diemenica	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epacris impressa	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Celmisia longifolia	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Deyeuxia monticola	1	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Blandfordia punicea	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eucalyptus nitida	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxylobium ellipticum	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia mucronata	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leptospermum glaucescens	1	-	1	1	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Bauera rubioides	1	1	-	1	1	1	1	1	-	-	1	1	-	-	-	-	-	-	-	-	1	1	-	1
Lepidosperma filiforme	1	1	1	-	-	1	-	1	-	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-
Pentachondra pumila	1	-	-	-	1	1	-	1	1	1	-	1	1	-	1	-	-	-	-	-	-	-	-	-
Cyathodes petiolaris	1	-	1	-	-	1	-	1	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-
Banksia marginata	-	-	1	1	1	1	-	1	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Diplarrena latifolia	1	-	1	-	-	1	-	-	1	1	1	1	1	-	1	1	-	1	-	-	-	-	-	-
Leptospermum nitidum	-	1	-	1	1	1	1	1	1	1	-	1	1	-	1	-	1	1	-	1	-	-	-	-
Melaleuca squamea	1	-	-	1	1	1	1	1	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-
Gymnoschoenus sphaerocephalus	-	-	-	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-	-
Lepyrodia tasmanica	-	1	-	-	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-
Empodismua minus	-	-	-	1	1	1	1	1	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	1	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-
Sprengelia incarnata	-	1	-	-	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Restio companatus	-	-	-	-	1	1	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Lycopodium laterale	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boronia citriodora	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraria capillaris	1	-	-	1	1	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Helichrysum pumilum	1	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera arcturi	-	-	-	-	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Xyris marginata	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hibbertia procumbens	-	-	-	-	1	-	-	1	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-
Schoenus tenuissimus	-	-	-	-	-	1	1	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Epacris serpyllifolia	-	-	-	-	-	-	1	-	1	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Pultenaea subumbellata	-	-	-	-	-	-	1	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-
Epacris lanuginosa	-	-	-	-	-	-	-	1	-	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-
Gleichenia alpina	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-
Baeckea gunniana	-	-	-	-	-	-	-	-	1	-	1	-	1	-	1	-	1	1	-	-	-	-	-	-
Microlaena tasmanica	-	-	-	1	-	-	-	-	1	-	-	1	-	1	1	1	1	1	1	-	1	1	-	-
Eucalyptus coccifera	-	-	-	-	-	-	1	-	-	-	-	1	1	-	1	1	1	1	-	-	1	-	-	-
Monotoca aff. *linofolia*	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	-	-	-	-	-
Poa gunnii	1	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-
Actinotus moorei	1	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-
Coprosma moorei	1	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Gonocarpus montanus	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-
Rubus gunnianus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	-	-	-	-	-	-	-

TABLE 3
Quartzite and Forest Communities

Species*	TWINSPAN 101			100													110					111		
	50	47	46	44	45	43	7	6	61	49	48	67	57	4	3	23	24	8	9	60	51	52	55
Lomatia polymorpha	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Persoonia gunnii	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Danthonia diemenica	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epacris impressa	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Celmisia longifolia	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Deyeuxia monticola	1	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Blandfordia punicea	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Eucalyptus nitida	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxylobium ellipticum	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia mucronata	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leptospermum glaucescens	1	-	1	1	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-
Bauera rubioides	1	1	-	1	1	1	1	1	-	-	1	1	-	-	-	-	-	-	-	-	1	1	-
Lepidosperma filiforme	1	1	1	-	-	1	-	1	-	1	1	1	-	1	-	-	-	-	-	-	-	-	-
Pentachondra pumila	1	-	-	-	1	1	-	1	1	1	-	1	1	-	1	-	-	-	-	-	-	-	-
Cyathodes petiolaris	1	-	1	-	-	1	-	1	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-
Banksia marginata	-	-	1	1	1	1	-	1	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-
Diplarrena latifolia	1	-	1	-	-	1	-	-	1	1	1	1	1	-	1	1	-	1	-	-	-	-	-
Leptospermum nitidum	-	1	-	1	1	1	1	1	1	1	-	1	1	-	1	-	1	1	-	1	-	-	-
Melaleuca squamea	1	-	-	1	1	1	1	1	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-
Gymnoschoenus sphaerocephalus	-	-	-	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	-	-	-	-	-
Lepyrodia tasmanica	-	1	-	-	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-
Empodismua minus	-	-	-	1	1	1	1	1	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	1	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-
Sprengelia incarnata	-	1	-	-	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-
Restio companatus	-	-	-	-	1	1	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Lycopodium laterale	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boronia citriodora	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraria capillaris	1	-	-	1	1	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Helichrysum pumilum	1	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera arcturi	-	-	-	-	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Xyris marginata	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hibbertia procumbens	-	-	-	-	1	-	-	1	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-
Schoenus tenuissimus	-	-	-	-	-	1	1	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
Epacris serpyllifolia	-	-	-	-	-	-	1	-	1	1	-	1	1	-	-	-	-	-	-	-	-	-	-
Pultenaea subumbellata	-	-	-	-	-	-	1	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-
Epacris lanuginosa	-	-	-	-	-	-	-	1	-	1	-	-	-	1	-	1	-	-	-	-	-	-	-
Gleichenia alpina	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	-	-	-	-	-	-	-	-
Baeckea gunniana	-	-	-	-	-	-	-	-	1	-	1	-	1	-	1	-	1	1	-	-	-	-	-
Microlaena tasmanica	-	-	-	1	-	-	-	-	1	-	-	1	-	1	1	1	1	1	1	-	1	1	-
Eucalyptus coccifera	-	-	-	-	-	-	1	-	-	-	-	1	1	-	1	1	1	1	-	-	1	-	-
Monotoca aff. *linofolia*	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	-	-	-	-
Poa gunnii	1	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
Actinotus moorei	1	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-
Coprosma moorei	1	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
Gonocarpus montanus	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-
Rubus gunnianus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	-	-	-	-	-	-

Species*	TWINSPAN 101			100												110					111			
	5 0	4 7	4 6	4 4	4 5	4 3	7	6	6 1	4 9	4 8	1 7	5 7	4	3	2 3	2 4	8	9	6 0	5 1	5 2	5 5	5 6
Lagenophora stipitata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-
Coprosma nitida	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	-	-	-
Cyathodes parvifolia	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	1	1	-	-
Drimys lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	1	1	-	-	-
Phyllocladus asplenifolius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	-	-	-
Trochocarpa cunninghamii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	1	1	1	1
Eucalyptus subcrenulata	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1	-	-	1	1	1	1
Nothofagus cunninghamii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	1
Richea scoparia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-
Astelia alpina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-
Gahnia grandis	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	1	1	1	1	-
Blechnum watsii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	1	1	-
Richea pandanifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	1	1	-	-
Tetracarpaea tasmanica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Trochocarpa gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Leptospermum langierum	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	-	1
Oxalis lactea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	1
Hymenophyllum cupressiforme	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-
Grammitis magellanica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-
Cyathodes juniperina	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Hakea epiglottis	-	1	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mitrasacme montana	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Campynaema lineare	1	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Exocarpos humifusus	1	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Lindsaya linearis	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monotoca submitica	-	-	1	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Restio australis	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Histiopteris incisa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Uncinia compacta	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Orites revoluta	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-

Additional species: 50, *Carpha alpina, Erigeron stellatus*; 47, *Eucryphia milliganii, Gnaphalium collinum*; 46, *Comesperma retusum, Callistermon viridiflorus*; 44, *Agastachys odorata*; 45, *Xyris muelleri*; 61, *Actinotus suffocata*; 57, *Gentianella dimensis, Oreobolus acutifolius*; 4, *Tetratheca procumbens*; 23, *Gaultheria hispida, Lissanthe montana, Scirpus aucklandicus*; 8, *Monotoca glauca, Leptospermum rupestre*; 9, *Athrotaxis cupressoides*; 51, *Aristotelia peduncularus, Drymophila cyanocarpa, Olearia persoonioides*; 52, *Anodopetalum biglandulosum, Atherosperma moschatum, Eucryphia lucida, Grammitis billardieri, Telopea truncata*; 55, *Uncinia tenella*; 56, *Pimelea drupacea*.

* Species shown in bold letters re the major differentiating species.

APPENDIX
Species Observed in the Study Area by Environment

Species*	Aquatic	Open	Scrub/ Forest	Herb	Eld. alpine	Dome alpine
Abrotanella scapigera (rh)	-	-	-	-	x	-
Acacia mucronata (s)	-	-	x	-	-	-
Acaena montana (rh)	-	-	-	x	x	-
Acaena novae-zelandiae (h)	-	-	x	x	-	-
Actinotus bellidioides (rh)	-	x	-	-	-	-
Actinotus moorei (rh)	-	x	-	-	-	-
Actinotus suffocata (rh)	-	x	-	-	x	x
Agastachys odorata (s/t)	-	x	x	-	-	-
Agrostis billardieri (g)	-	-	-	x	-	-
Agrostis parviflora (g)	-	-	-	x	-	x
Agrostis meionectes (g)	x	-	-	-	-	-
Agrostis venusta (g)	-	-	-	x	-	x
Apteropteris applanata (f)	-	-	x	-	-	-
Archeria serpyllifolia (s)	-	-	-	-	x	-
Aristotelia peduncularis (s)	-	-	x	-	-	-
Asperula gunnii (h)	-	x	-	x	-	-
Astelia alpina (gr)	-	x	x	x	x	x
Atherosperma moschatum (t)	-	-	x	-	-	-
Athrotaxis cuppressoides(t)	-	-	x	-	-	-
Athrotaxis selaginoides (t)	-	-	x	-	-	x
Baeckea gunniana (s)	-	x	-	-	x	x
Banksia marginata (s)	-	-	x	-	-	-
Baumea arthrophylla (gr)	x	-	-	-	-	-
Bauera rubioides (ss)	-	x	x	-	-	x
Bellendena montana (s)	-	x	x	-	x	x
Billardiera longiflora (ss)	-	-	x	-	-	-
Blandfordia punicea (gr)	-	x	-	-	-	x
Blechnum chambersii (f)	-	x	x	-	-	x
Blechnum penna-marina (f)	-	x	x	-	x	-
Blechnum wattsii (f)	-	-	x	-	-	-
Boronia citriodora (s)	-	x	x	-	-	-
Brachycome spathulata (rh)	-	-	-	-	x	-
Caladenia sp. (gr)	-	-	x	-	-	-
Campynema lineare (gr)	-	x	-	x	x	x
Carex aff. *appressa* (gr)	-	x	-	x	x	x
Carex gaudichaudiana (gr)	x	-	-	x	-	-
Carpha alpina (gr)	-	x	-	x	x	x
Carpha curvata (gr)	-	-	-	-	x	x
Carpha rodwayi (gr)	-	-	-	-	x	-
Celmisia longofolia (rh)	-	x	-	-	-	x
Celmisia saxifraga (rh)	-	-	-	-	x	-

* Key: c — cushion, f — fern, g — grass, gr — graminoid, h — herb, m — moss, rh — rosette, s — shrub, ss — scrambling shrub, s/t — shrub/tree, t — tree

Species	Aquatic	Open	Scrub/ Forest	Herb	Eld. alpine	Dome alpine
Cenarrhenes nitida (s)	-	x	x	-	-	-
Centrolepis monogyna (c)	-	x	-	-	x	x
Coprosma moorei (ss)	-	x	-	-	-	-
Coprosma nitida (s)	-	x	x	-	x	x
Coprosma perpusilla (ss)	-	-	-	-	x	-
Cotula alpina (rh)	-	-	-	x	x	-
Cyathodes dealbata (ss)	-	-	-	-	x	x
Cyathodes parvifolia (s)	-	x	x	-	-	-
Cyathodes petiolaris (s)	-	x	-	-	x	-
Cyathodes straminea (s)	-	x	x	-	x	x
Danthonia fortunae-hibernae (g)	-	-	x	-	x	x
Danthonia pauciflora (g)	-	-	-	-	x	x
Danthonia diemenica (g)	-	x	-	-	-	-
Deyeuxia monticola (g)	-	x	-	x	x	x
Dichosciadium ranunculaceum (rh)	-	-	-	-	x	-
Diplarrena latifolia (gr)	-	x	x	x	x	x
Diplaspis cordifolia (rh)	-	x	-	x	x	x
Diselma archeri (s)	-	-	-	-	x	-
Donatia novae-zelandiae (c)	-	-	-	-	x	-
Dracophyllum minimum (c)	-	-	-	-	x	-
Drimys lanceolata (s)	-	-	x	-	x	x
Drosera arcturi (h)	-	x	x	-	x	x
Drosera pygmaea (rh)	-	-	-	x	-	-
Drymophila cyanocarpa (h)	-	-	x	-	-	-
Eleocharis acuta (gr)	x	-	-	-	-	-
Eleocharis pusilla (gr)	x	-	-	-	-	-
Empodisma minus (gr)	-	x	x	-	x	x
Epacris impressa (s)	-	x	-	-	-	-
Epacris lanuginosa (s)	-	x-	-	-	-	-
Epacris serpyllifolia (s)	-	x	x	-	x	x
Epilobium spp. (h)	-	-	-	x	-	-
Erigeron stellatus (rh)	-	x	-	-	x	x
Eucalyptus coccifera (t)	-	-	x	-	-	-
Eucalyptus delegatensis (t)	-	-	x	-	-	-
Eucalyptus nitida (t)	-	x	x	-	-	-
Eucalyptus subcrenulata (t)	-	-	x	-	-	-
Eucryphia lucida (t)	-	-	x	-	-	-
Eucryphia milliganii (t)	-	-	x	-	-	-
Euphrasia gibbsiae (h)	-	-	-	-	x	-
Euphrasia striata (h)	-	-	-	-	x	x
Ewartia meredithae (c)	-	-	-	-	x	-
Exocarpos humifusus (ss)	-	x	-	-	x	x
Gahnia grandis (gr)	-	-	x	-	-	-
Gaimardia fitzgeraldii (c)	-	-	-	-	x	-
Gaultheria hispida (s)	-	-	x	-	x	x
Gentianella diemensis (h)	-	x	-	-	x	x
Geranium potentilloides (h)	-	-	x	-	x	-

Species	Aquatic	Open	Scrub/ Forest	Herb	Eld. alpine	Dome alpine
Gleichenia alpina (f)	-	x	x	-	-	x
Gnaphalium collinum (h)	-	x	-	x	x	x
Gnaphalium traversi (h)	-	-	-	-	x	-
Gnaphalium umbricola (h)	-	-	x	-	-	x
Gonocarpus micranthus (h)	x	-	-	x	-	x
Gonocarpus montanus (h)	-	x	x	-	x	x
Grammitis billardieri (f)	-	-	x	-	-	-
Grammitis magellanica (f)	-	-	x	-	-	-
Gymnoschoenus sphaerocephalus (gr)	-	x	x	-	-	-
Hakea epiglottis (s)	-	x	x	-	-	-
Helichrysum acuminatum (rh)	-	-	-	-	-	x
Helichrysum backhousii (s)	-	-	-	-	x	x
Helichrysum hookeri (s)	-	x	-	-	-	-
Helichrysum milliganii (rh)	-	-	-	-	x	x
Helichrysum pumilum (rh)	-	x	-	-	-	-
Helichrysum scorpioides (h)	-	x	-	x	x	x
Herpolirion novae-zelandiae (gr)		-	-	x	-	-
Hibbertia procumbens (ss)	-	x	-	-	-	x
Hierochloe fraseri (g)	-	-	-	-	x	-
Histiopteris incisa (f)	-	-	x	-	-	-
Hydrocotyle sibthorpioides (h)		-	x	x	x	-
Hypericum japonicum (h)	-	-	-	x	-	-
Hymenophyllum australe (f)	-	-	x	-	-	-
Hymenophyllum cupressiforme (f)	-	-	x	-	-	-
Isoetes gunnii (f)	x	-	-	-	-	-
Juncus spp. (gr)	x	-	x	x	x	-
Lagenophora stipitata (rh)	-	x	x	-	x	-
Lepidosperma filiforme (gr)	-	x	x	-	-	-
Lepidosperma inops (gr)	-	-	-	-	x	-
Leptomeria glomerata (ss)	-	x	-	-	x	x
Leptospermum glaucescens (s)	-	x	x	-	-	-
Leptospermum lanigerum (s)	-	-	x	-	-	-
Leptospermum nitidum (s)	-	x	x	-	-	-
Leptospermum rupestre (ss)	-	x	x	-	x	x
Lepyrodia tasmanica (gr)	-	x	x	-	-	-
Lindsaya linearis (f)	-	x	-	-	-	-
Lissanthe montana (s)	-	x	-	-	-	-
Lomatia polymorpha (s)	-	-	x	-	-	-
Luzula spp. (gr)	-	x	-	-	x	x
Lycopodium australianum (f)	-	-	-	-	x	-
Lycopodium fastigiatum (f)	-	x	x	x	x	x
Lycopodium laterale (f)	-	x	-	-	-	x
Lycopodium scariosum (f)	-	-	-	-	-	x
Melaleuca squamea (s)	-	x	x	-	-	-
Microcachrys tetragona (ss)	-	-	-	-	x	x
Microlaena tasmanica (g)	-	x	x	x	x	x
Microseris scapigera (rh)	-	x	-	-	-	-

Species	Aquatic	Open	Scrub/ Forest	Herb	Eld. alpine	Dome alpine
Microtis unifolia (gr)	-	x	-	-	-	-
Milligania densiflora (gr)	-	x	-	-	x	x
Milligania lindoniana (gr)	-	-	-	-	x	-
Mitrasacme archeri (c)	-	-	-	-	x	-
Mitrasacme montana (h)	-	x	-	-	x	x
Monotoca glauca (s)	-	-	x	-	-	-
Monotoca linifolia (s)	-	-	x	-	x	x
Monotoca submutica (s)	-	-	x	-	-	-
Myriophyllum aquatica (h)	x	-	-	-	-	-
Myriophyllum pedunculatum (h)	x	-	-	-	x	-
Nothofagus cunninghamii (t)	-	-	x	-	x	x
Nymphoides exigua (h)	x	-	-	-	-	-
Olearia erubescens (s)	-	x	x	-	-	-
Olearia ledifolia (s)	-	-	-	-	x	x
Olearia obcordata (s)	-	x	-	-	-	-
Olearia persoonioides (s)	-	-	x	-	-	-
Olearia pinifolia (s)	-	-	x	-	x	-
Oreobolus acutifolius (c)	-	x	-	-	x	x
Oreobolus pumilio (c)	-	x	-	x	x	x
Oreomyrrhis ciliata (rh)	-	x	-	-	-	-
Orites acicularis (s)	-	-	-	-	x	-
Orites revoluta (s)	-	x	x	-	x	x
Ourisia integrifolia (h)	-	-	-	-	x	-
Oxalis lactea (rh)	-	x	x	-	x	-
Oxylobium ellipticum (s)	-	x	-	-	-	x
Pentachondra pumila (ss)	-	x	-	-	x	x
Persoonia gunnii (s)	-	x	x	-	x	x
Persoonia muelleri (s)	-	x	-	-	-	-
Phyllocladus aspleniifolius (t)	-	-	x	-	-	x
Pimelea drupacea (s)	-	-	x	-	-	-
Pimelea lindleyana (s)	-	x	x	-	-	-
Pimelea sericea (s)	-	-	x	-	x	-
Plantago daltonii (rh)	-	-	x	x	-	-
Plantago paradoxa (rh)	-	-	-	-	-	x
Plantago tasmanica (rh)	-	-	-	-	x	x
Poa gunnii (g)	-	x	-	x	x	x
Podocarpus lawrencei (ss)	-	-	x	-	x	x
Polystichum proliferum (f)	-	-	x	-	x	-
Prasophyllum sp. (gr)	-	-	-	-	-	x
Pterygopappus lawrencei (c)	-	-	-	-	x	-
Pultenaea dentata (s)	-	x	-	-	-	-
Pultenaea subumbellata (s)	-	x	-	-	-	-
Ranunculus sp. (rh)	-	-	-	x	-	-
Ranunculus collinus (rh)	-	-	-	x	-	-
Ranunculus rivularis (h)	x	-	-	-	-	-
Restio australis (gr)	-	x	-	-	-	-
Restio complanatus (gr)	-	x	-	-	-	x

Species	Aquatic	Open	Scrub/ Forest	Herb	Eld. alpine	Dome alpine
Richea gunnii (s)	-	x	-	-	-	-
Richea pandanifolia (s)	-	x	x	-	x	x
Richea scoparia (s)	-	x	x	-	x	x
Richea sprengelioides (s)	-	-	-	-	x	x
Rubus gunnianus (rh)	-	x	-	-	x	x
Scaevola hookeri (h)	-	-	x	-	x	-
Schoenus calyptratus (gr)	-	-	-	-	x	x
Schoenus fluitans (gr)	x	-	-	-	-	-
Schoenus tenuissimus (gr)	-	x	x	-	-	-
Scirpus aucklandicus (gr)	-	x	-	x	-	-
Scirpus crassiusculus (gr)	x	-	-	-	-	-
Scirpus fluitans (gr)	x	-	-	-	-	-
Senecio gunnii (h)	-	-	x	-	x	-
Senecio leptocarpus (rh)	-	-	-	-	-	x
Senecio pectinatus (rh)	-	x	-	-	x	x
Sphagnum cristatum (m)	x	x	-	-	-	-
Sprengelia incarnata (s)	-	x	x	-	x	x
Spyridium gunnii (s)	-	-	x	-	x	-
Sticherus tener (f)	-	-	x	-	-	-
Stylidium graminifolium (rh)	-	x	x	-	-	x
Telopea truncata (s)	-	-	x	-	x	x
Tetracarpeae tasmanica (s)	-	-	x	-	-	-
Tetraria capillaris (gr)	-	x	x	-	-	-
Tetratheca procumbens (s)	-	x	-	-	-	-
Thelymitra venosa (gr)	-	x	-	-	-	-
Trithuria submersa (gr)	x	-	-	-	-	-
Trochocarpa cunninghamii (ss)	-	-	x	-	-	-
Trochocarpa gunnii (s)	-	-	x	-	-	-
Uncinia compacta (gr)	-	x	-	-	x	x
Uncinia tenella (gr)	-	-	x	-	-	-
Utricularia dichotoma (h)	x	-	x	-	-	-
Viola hederacea (rh)	-	x	-	-	x	x
Wahlenbergia saxicola (rh)	-	-	-	-	x	-
Xyris marginata (gr)	-	x	-	-	-	-
Xyris muelleri (gr)	-	x	-	-	-	-

WILLIAM SAVILLE-KENT, F.L.S., F.Z.S., F.R.M.S. (1845–1908)

by A. J. Harrison

(with an appendix)

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William Saville-Kent pioneered the scientific management of fisheries in Australia from 1884 to 1907. His wide-ranging research interest extended from infusoria to salmon and he worked in Britain, off Portugal, and in every part of Australia from Thursday Island in the north to Tasmania in the south. He cultured a number of marine species and was a leader in the movement to utilise the great Victorian public aquaria for scientific purposes. His prolific pen delineated Australia's commercial fish resources, and brought to Europe, for the first time, the diversity and scale of the Great Barrier Reef.

Key Words: Saville-Kent, fisheries, salmon, oysters, aquaria, Great Barrier Reef, Tasmania, Queensland, Victoria, Western Australia.

INTRODUCTION

William Saville-Kent was 38 years old when he was offered the post of Superintendent and Inspector of Fisheries in Tasmania and the opportunity to become a major figure in the early development of Australian fisheries.

He was born William Savill Kent on 10 July 1845 at Cliff Cottage in Sidmouth, Devon, the youngest of the ten children of Samuel Savill Kent and Mary Ann Kent (nee Windus). His grandfather, Samuel Luck Kent, had been a prosperous carpet manufacturer in London where William's father worked until becoming a partner in a company of dry salters. His mother was the daughter of a wealthy coach builder, Thomas Windus, who later became a Fellow of the Royal Society of Antiquaries; she was a well educated and a "gentle gracious woman" (Taylor 1979: 42). After some health problems, Samuel moved the family to Devon. He became Sub-Inspector of Factories in 1834, a highly paid and prestigious position, supervising the new Factories Act in southwestern England. In 1840 the family acquired a governess, Mary Drewe Pratt, for Mary Ann and Elizabeth, their two surviving daughters. Mary Pratt and Samuel Kent quickly formed an intimate relationship which was to have tragic consequences 20 years later.

The death in infancy of five of William's siblings, the seniority of his only brother Edward Windus (13 years older) and his commitment to a career at sea, ensured that William formed a deep bond and mutual commitment with his sister, Constance Emily, who was a little over a year his senior. As their mother's health deteriorated and their father's involvement with the governess grew, Constance's initial close friendship with the latter first cooled and then turned to hatred when her mother died in May 1852. Even whilst Mrs Kent was alive, her husband had openly consorted with Miss Pratt (and other women) and the governess had derided her to the children. In 1848, the family moved to Walton Manor and then to Baynton House in East Coulston, Wiltshire. Samuel married Miss Pratt a little over a year after his first wife died and by 1858 had three children by her — Mary Amelia born 1855, Frances Savill born August 1856 and Eveline born October 1858. The family home was now Road Hill House near Trowbridge on the border of Wiltshire and Somerset.

As her father and stepmother were now committed exclusively to the new family, the determined and mature Constance dressed in her brother's clothes and, after he had cut her hair, set off with the 11-year-old William in tow bound for Bristol and any ship that might take them to a new life. Two days later they were found at Bath and returned, William contrite but his sister defiant. (Taylor (1979: 58) believed their escapade inspired Dickens to write *Edwin Drood* in 1870.) Due to Samuel's financial position, Constance and William were being taught at home by their stepmother prior to this escapade but they were now sent off to boarding school, his in Worcester. In his early teens, William attended another boarding school in Gloucester, where he was in 1858 when his brother Edward died in Cuba.

In June 1860 the family was living at Road Hill House when the 16-year-old Constance murdered her stepbrother Frances Savill. She had considered killing her stepmother but killed the boy to cause greater agony to the woman who had tormented her mother. Constance and William and a servant were suspected of the crime. Suspicion fell on William "because of his close attachment to his sister" (Taylor 1979:191) but he was not seriously suspected due to his gentle nature and to the fact that when they had run away he "proved a most inefficient and unheroic partner".

A long and sensational investigation failed to allow committal of anyone for the crime. Samuel urged a reward be offered and openly stated his belief that a mentally unbalanced Constance was guilty. He blamed Constance's condition on his first wife, claiming she was insane and that insanity was prevalent in the Windus family. At this time such a claim, if believed, would have severely jeopardised the future opportunities of all four surviving children of Mary Ann including William. The publicity forced Constance to complete her education in France, after which, in August 1863, she found seclusion in a Church of England convent in Brighton under the name Emilie.

In 1865 she confessed her crime, first to Reverend Wagner at the convent and then formally to the authorities. In order not to prejudice William's career, she refused to accept the advice of her counsel to plead insanity: "her self-sacrifice did her great credit but denied her the possibility of a possible escape route from the hangman" (Taylor 1979: 294). Her plea of guilty was also "to clear those unjustly suspected". She was duly sentenced to death but the sentence was commuted to life imprisonment. At the time of her trial she was said to be the best known woman in England and her effigy stood in Madame Tussaud's Waxworks until 1877.

After the murder, the family moved to Weston-super-Mare, where Florence Savill Kent was born on 19 July 1861 (Acland Savill Kent was born at Road Hill House on 30 July 1860). Shortly after moving to Weston-super-Mare, Samuel was advised that the headquarters of the Factories Commission were to be moved to Wrexham and that he would need to transfer to north Wales. In August 1866, William's stepmother died at the family's new home in Llangollen, Wales; his father moved north to Denbigh with the younger children, whilst William and his elder sisters, Elizabeth and Mary Ann, moved to London where, aged 21, he sought a career as a naturalist.

LIFE AND WORK IN ENGLAND

The attached bibliography indicates that Saville-Kent left a very substantial body of literature, including some personal correspondence, but it contains very little material to illuminate his persona. The author is indebted to the biographer of Constance Savill Kent (Taylor 1979) for most of the above information on Saville-Kent's boyhood and family.

William had spend much of his life near the sea and his father was a senior civil servant but, apart from these circumstances, there is no obvious reason why William should choose a vocation as a naturalist. At Kings College he qualified to enter the Imperial Civil Service. After further studies in biology and laboratory techniques under Prof. T. H. Huxley at the Royal School of Mines, he obtained his first permanent position at the British Museum in 1869 (Queensland University Enquiry 1891) under the distinguished naturalist Sir Richard Owen, superintendent of the natural history collections. Previously Saville-Kent held short-term positions in the museum of the Royal College of Surgeons and the Cambridge Museum of Comparative Anatomy. His association with the British Museum actually began in October 1868 when, aged 23, he was paid £50 to "name, arrange and make a manuscript catalogue" of the museum's collection of Madreporaires (stony corals). This task brought him into contact with Australian marine fauna for the first time and his competence so impressed Owen and the Keeper of the Zoology Department, Dr John E. Gray, that they arranged a permanent position for him as a junior assistant in the Department of Geology. The post carried a salary of £90 per annum and he took up the position in November 1869.

Saville-Kent was accepted as a fellow of the Zoological Society of London in December 1869, being at that time a curator in the Zoology Department of the Museum, and in May 1870 his supervisor, G. R. Waterhouse (Keeper of the Geology Department of the Museum), recommended that he be given five weeks extra leave to accept the offer of Mr Marshall Hall, F.G.S., to place his yacht *Norna* at William's disposal for the purpose of conducting an expedition to dredge for marine specimens and survey for fish in Vigo Bay, off the coast of Spain and Portugal. He had been introduced to Hall by Henry Lee, F.L.S., the President of the Croydon Microscopical Society. This survey, which was supported by a grant of £50 from the Royal Society of London, provided him with the material on

which to write his first scientific papers and the first opportunity to survey the marine life of a "new" area. The plan of the expedition was to start in Vigo Bay and work towards Lisbon and then to the deep-sea fishing grounds of Setubal where it was hoped to find specimens of the glass rope sponge (*Nature* 5 October 1871: 457).

In March 1871, in a letter to Dr P.L. Sclater, the secretary of the Zoological Society (Zool. Soc. files), Saville-Kent complained of the "lamentable stagnation of affairs at the British Museum" and stated his intention

> "to apply for the post of curator at the Leeds Museum ... Should I leave now I shall doubtless return again some day and the experience gained in the faithful discharge of the responsibilities of a small but independent position will further qualify me for one of still greater responsibility hereafter."

When not selected for the post in Leeds he continued at the British Museum until circumstances the next year again forced him to seek a more permanent and challenging position. In February 1872 his father died in Wales and in June he married Elizabeth, the eldest daughter of Thomas Randle Bennett, a London barrister of 5 Kings Bench Walk, Temple. By the end of the year he found an opportunity to study the new field of pisciculture as curator of the Brighton Aquarium. The Minutes of the meeting of the Trustees of the British Museum on 8 February 1873 record that Dr Waterhouse

> "called attention to the value of Mr Kent's services in the Museum and expressed his great regret that an inadequate salary should have obliged Mr Kent to seek elsewhere for a more favourable application of his acquirements."

The use of aquaria in the scientific study of fishes was one of his life-long interests and a particular ambition was to see established a British Marine Research Station along the lines of one already established in Naples. His first attempt was in Jersey through the Channel Island Zoological Station, Museum and Institute of Pisciculture Society Limited, 16 Royal Square, St Heliers. By February 1870, £1000 had already been raised and a further £500 promised from leading residents of the island. Saville-Kent approached the Royal Society for a small grant to aid the project in 1870. The aquarium was one of a succession of crazes associated with the Victorian interest in natural history. Barber (1980: 117) records the "invention" of the aquarium as occurring in 1850, and soon after they were a common feature of every drawing room. Although the home aquarium craze ended about 1870 it was replaced by a "sudden fashion in huge purpose-built public aquaria ... every large town in England was clamouring to have its own aquarium" (*ibid.*: 123). The later reduction of public interest in these facilities offered superb research opportunities generously funded by government grants and supplemented by entrance fees. Bertram (1873) stated

> "The Brighton and Crystal Palace aquaria will do much to spread a correct knowledge of the life and habits of all kinds of fish ... I am in hopes that real good work will yet be achieved by means of these aquaria, and that many points of fish life and economy, especially as regards our food fishes, will be determined by Mr Lloyd at Brighton and Mr Saville-Kent at the Crystal Palace. In particular I hope that one or other of these gentlemen will solve a great many of the questions which have been promulgated during late years in regard to the acclimatisation in this country of various kinds of foreign fish ... The real value of these institutions will consist in their solving the problems connected with our food fishes" (*ibid.*: 295-296).

During Saville-Kent's time at Brighton he carried out research and wrote a guide book to the Aquarium. Several articles in *Nature* (see Appendix) record his observations of a diverse range of marine animals ranging from porpoises to sea horses and octopus. His research included the detailed observation of the behaviour of the species held for display; one such study, observation of the copulation of the octopus, eventually led to his resignation. The circumstances are described in a reply he wrote to a request from Professor Sir Richard Owen for details of the octopus behaviour (Owen Correspondence, Vol.XVI, B.M.N.H., 1 July 1873). He had been supported in his application for the Brighton position by a Mr Lee, the effective director of the facility, but Saville-Kent with his enthusiasm and drive was soon looked on by the Board "as their chief officer ... responsible for the entire management of the tanks and their contents". Lee's earlier sponsorship of the young scientist became tinged with jealousy when the Board planned to introduce his protege to the King of the Belgians as "curator and chief officer in charge". Later, after witnessing the intriguing sex life of the octopus, Saville-Kent reported the details to the Board and "sent a brief note to several of the papers". By his account, Lee suggested they write a joint paper of the observations and he agreed but did not tell of his letters to the papers as he

"thought it rather hard that I might not reap the credit of my own observations". When Lee read one of these letters in *The Times* he accused Saville-Kent of "duplicity and disingenuousness" which left the latter with "no option, in the light of our former friendship and services but to resign". He did not appeal to the Board and his resignation was accepted but when his father-in-law heard of the events he concluded that William "had been the victim of a cowardly plot" and vowed to have the Board reconsider his appointment. Bennett was successful, in that the Board reviewed the situation at its next meeting, but Saville-Kent did not seek reinstatement. On leaving Brighton he published an article describing the facility, its construction and recommendations for overcoming some of its deficiencies (Saville-Kent 1873c).

Judging from the comments of Bertram (1873), Saville-Kent left Brighton to hold briefly a similar position at the Crystal Palace in London. In June 1873 he had been elected a Fellow of the Linnaean Society of London and with his new qualification and experience at Brighton he took control of the Manchester Aquarium in Alexander Park. Some appreciation of his work there can be gained from his guidebook published in 1875, his paper on the culture of lobsters which reported the work he had done in the summer of 1874, and an article in *Nature* concerning echinoderms (1883a). The death of his young wife Elizabeth in 1875 after only three years of marriage probably caused him to leave Manchester and move to the aquarium at Great Yarmouth in Norfolk and then return to Jersey.

The Channel Islands project was slow to develop and in March 1877, after another unsuccessful approach for support to the Royal Society, he took a temporary position with the Zoological Society restoring their Aquarium and Fish House in Regents Park. On 26 October 1877 he excitedly wrote to Sir Richard Owen (Owen Correspondence, Vol.XVI, B.M.N.H. 26 October 1877:) that

> "at length a definite prospect of accomplishing what I may say has been the main object of my ambition during my several years 'Apprenticeship' as naturalist to the leading English Aquaria. Namely the establishment of an institution specially devoted to the interests of marine zoology and pisciculture and that I shall place at the disposal of British Naturalists facilities for pursuing marine biological research which under existing auspices can be obtained no nearer than Naples."

He expressed disappointment that the facility has to be financed by way of a public company rather than "private munificence" but acknowledged that "now-a-days [science] must make the most of such opportunities that present themselves".

The aquarium was to be financed by public shares valued at £1 each. The company was registered in Jersey in October 1877 and Saville-Kent expected "that by January next we shall be in a position to commence active building". He invited Owen to be a member of the Technical Committee that would be appointed to advise on research priorities. In early 1878 he was confident "of starting the technical department ... a number of rooms for the use of students had been equipped together with a depot for supplying specimens for various museums and schools". By April he was confident of commissioning the permanent buildings and hoped that, as the British Association had recently donated £100 to the Naples laboratory, "charity would be as judiciously bestowed nearer home". But the project could not be firmly established and in 1879 he took up a position of curator at the new Brighton Aquarium.

Early in 1883 he was pleased to note that "a fine series of marine and freshwater tanks" being built for the International Fisheries Exposition would be left in position and "their final destiny having alone to be decided on" (1883). He proceeded to nominate a range of options which would see this facility incorporated in one of the nearby institutions, but again it seems his high hopes appear not to have eventuated. In January 1884 he gathered together a group of leading marine biologists including W.H. Flower, President of the Zoological Society, Professor Mosely of Oxford, and G.J. Romanes, Secretary of the Linnaean Society, who were prepared to support his proposal to convert the Brighton Aquarium into the British Marine Research Station. A printed circular was prepared and he addressed the Zoological Society on the subject. His appointment to Tasmania forced him to "leave the future of the project in the hands of my friend Dr Romanes", but his interest in these facilities continued in Australia, where he built a research station in Hobart and successfully reared and studied a number of local species; he also urged the Queensland Government to establish another on Thursday Island.

His interest in fisheries as distinct from marine biology appears to have begun early in 1870 with the cruise of the Norna and then progressed through his association with the various public aquaria. When Spencer Walpole left the post of British Inspector of Fisheries to become Governor-

General of the Isle of Man in April 1882, Saville-Kent sought the position through his friend Sclater, and probably Huxley who also held such a position.

He married Mary Ann Livesey in the spring of 1876 — "a young woman of some financial means ... who was to become a great champion of his work" (Taylor 1979: 352). At the time of his appointment (1884) they were living in London at Aston House, 87 St Stephens Avenue, Uxbridge Road, Shepherds Bush, and he was working under Huxley at the Buckland Fisheries Museum in South Kensington. In writing to Dr Sclater on 24 March 1884 he said "I have unexpectedly been offered an appointment in Tasmania ... I intend to accept and will leave in June."

TASMANIA

Following a Royal Commission in 1882 the Tasmanian Government had commissioned the Chief Inspector of Irish Fisheries, Thomas Brady, to recruit "someone who understood both pisciculture and ostreiculture". Brady consulted Huxley who recommended Saville-Kent and Brady immediately offered him the position. A formal contract between him and the Tasmanian Government was signed on 17 April 1884 in London, requiring him to work until 28 May 1887 at the exclusive direction of the Chief Secretary "or other duly authorised officer". Saville-Kent left Gravesend on 28 May 1884 and after a passage of seven weeks on the Orient steamer *John Elder* reached Melbourne. He arrived in Launceston with his wife and 29-year-old step-sister Mary Amelia, by now a governess, on the *Mangana* on 15 July. They immediately travelled on to Hobart, arriving the next evening.

The acquisition of Saville-Kent by the Tasmanian Government was greeted with acclaim. His writings to date included an authoritative three-volume monograph on infusoria and another on British fishes commissioned by the London Fisheries Committee, together with the guidebooks to the Manchester and Brighton Aquaria, and 19 scientific papers. He was clearly familiar with the new oyster culture techniques developed by Coste in France and Hubracht in Holland, both being based on much earlier developments in Lake Fusaro in Italy, and brought to England by Buckland. Whilst he may not have had practical experience in oyster culture, he had cultured the European lobster whilst working at the Manchester Aquarium in 1871 and presented a paper describing the technique at the International Fisheries Exhibition held in London in 1883. He was reported to be the first person to demonstrate that the popular "whitebait" was in fact the juvenile stages of the herring.

The *Hobart Mercury* (26 July 1884) announced that he

> "enters upon his duties as Inspector of Tasmanian fisheries with very ample qualifications and the colony appears exceedingly fortunate in obtaining the services of one who has such a wide practical knowledge not only in the particular branch of science to which he will ... direct his particular attention, but in all departments that may serve to aid him in his researches".

The *Tasmanian Mail* used similar words in its article of 2 August 1884. E.N.C. Braddon, M.H.A., referred to him as "a gentleman who was second to none ... as an expert". In the same debate, E. Shoobridge, M.H.A., related how in a recent visit to the U.S.A. "he had interviewed one of the professors of the Smithsonian Institute on the subject and he had said they had in Mr Kent one of the best men in the world for this sort of work" (*The Mercury* 12 September 1884). With the endorsement of Huxley, these comments were amply justified.

The introduction of European oyster culture techniques was perhaps Saville-Kent's best known contribution to Tasmania. Within three months of his arrival he had visited the Little Oyster Cove beds established by Captain Stanley's Tasmanian Oyster Culture Association and comprehensively reported on their condition and how new techniques could be applied. In his first year he spent ten days studying the east coast oyster beds and made visits to Cloudy Bay. He described his work in a paper he wrote for the meeting of the Australasian Association for the Advancement of Science held in Christchurch, New Zealand, in 1891, entitled "On oyster and oyster culture in Australasia", and in the reports of the Fisheries Department between 1884 and 1888 (see Sumner 1972). He cultured both the Sydney rock and New Zealand oysters in an attempt to improve the industry; however, his work in aquaculture was not confined to oysters. Immediately upon his arrival he recommended the establishment of saltwater ponds to culture local species such as the real trumpeter (*Lates hecateia*), the freshwater species (*Prototroctes marana* known as the grayling or cucumber mullet) and the giant freshwater crayfish, to restore overfished stocks. The introduction of exotic species is now known to have produced catastrophic effects in the ecology

of several countries, but the latter half of the nineteenth century was a period when exotic species of both plants and animals were still being established in Europe and abroad. Saville-Kent arrived in Tasmania with the intention of expanding the acclimatisation programme, started with salmonids, to encompass prized marine species from European waters such as cod, herring, soles, flounder and lobsters. (With the benefit of hindsight it is perhaps fortunate that he left the State before these imports arrived as the destructive effect of trout on the indigenous fresh-water fauna was already noticeable.) Saville-Kent also proposed to send the "trumpeter", which he had successfully cultured at Battery Point, to England for introduction into the waters off the Devon coast. The Tasmanian flounder was also reared at this research facility and both these species are again being considered as subjects for aquaculture research 100 years later.

He described many new species of fish and was an active member of the Royal Society of Tasmania and a contributor to its meetings. His contribution to the establishment of salmonids is confused by the controversy with the Salmon Commissioners, which eventually lead to him leaving Tasmania. Nevertheless, at least in his first few years, he spent much time improving the technology of salmonid culture, expanding the Plenty facility and designing new hatching troughs. During his first year in Tasmania he made 19 separate visits to the Salmon Ponds, working in harmony with the staff of the Commission. His paper to the Royal Society in 1887 (see bibliography) described suggestions to overcome the critical problems facing the acclimitisation programme and demonstrated his knowledge of the salmonid disease then affecting fish at Plenty. He also proposed using the Battery Point establishment to rear and hold brood stock of salmon in sea water. He did succeed in culturing the cucumber mullet, being assisted by Lt C.E. Beddome, R.N., and restocked some rivers.

His most lasting contribution was not in the field of aquaculture but in laying the foundation of government management of wild fisheries. Rejecting the claims by some fishermen of the "destructive nature" of crayfish pots, he strongly supported the introduction of a legal minimum size for crayfish and succeeded in having the Act for the Protection of Crayfish approved by Parliament in December 1885. This legislation has ensured the protection of crayfish stocks for over 100 years despite intensive pressure in the past 30 years — the present legal minimum size is still close to the same overall length. He also supported the claims of commercial fishermen in their campaign to obtain a more reasonable balance between their needs and the protection of salmonids in estuaries. He recognised the need for both enlightened management policies and effective enforcement of them — in early 1885 he spent two days as an expert witness in a "test case" on illegal netting heard at New Norfolk.

The management of fisheries depends on accurate and comprehensive statistics on fishing methods, areas, fishing effort and landings. Saville-Kent began the routine collection of such information from fishermen, building on the early work of R.M. Johnston for the 1882 Royal Commission. As part of the data collection he proposed that all fishing vessels be registered and identified by numbers (a device introduced in England in 1868 and throughout Europe after 1902). This scheme was authorised by the *Fisheries Act* 1889 and has continued thereafter. The editor of the *Tasmanian News* eloquently endorsed his achievements following the tabling of his report for 1885–86 and particularly praised his endeavours to fight the pollution of the Derwent, where not only was sewerage a problem, but chemical pollution from industries such as the gas works was contaminating and killing fish.

His commitment to improved technology was characteristic of his outlook and reflected his breadth of knowledge and receptivity to new ideas. He brought to Tasmanian the blossoming fisheries technology and research occurring in Europe in the last quarter of the nineteenth century, and fostered in Tasmania some of the public interest in fisheries epitomised by the great Exhibitions held in London, Edinburgh and several European cities.

> "Now in order to keep abreast of the times in association with the profitable utilisation of nature's productions, it is incumbent at the present day, to abandon the unskilled and haphazard methods of former years, and conduct every operation on a thoroughly scientific basis" (Saville-Kent 1891).

He demonstrated that the trammel net was far superior to the seine net which had until then been the mainstay of the industry. In 1886 he imported and demonstrated the otter trawl and also introduced the long-line to Tasmanian fishing. He was probably the first "developer" to discover the deep conservatism of Tasmanian fishermen, "[they] do not want to increase the supply of fish ... [and] the introduction of new methods ... would not be acceptable" (Fisheries Department Report 1886).

After leaving Tasmania he reflected on this subject, in his Presidential Address to the Royal Society of Queensland in 1889 (published 1891) referred to above:

> "Doubtless due to the true conservative instinct that distinguishes fishermen all over the world, the great majority of those engaged in this important industry will be content to continue working along the same groove with which they are alone familiar reaping all they can of the grand harvest of the sea from where they have not sown and without the slightest care or compunction for the reapers that follow after" (*ibid.*).

In 1886 he returned to England for a brief time apparently to be present when his sister was finally released from gaol and when he returned he was accompanied by Constance who would hereafter call herself Ruth Emily Kay and claim that she arrived in Australia in 1868. She remained with William and Mary Ann until 1889.

The circumstances under which Saville-Kent left Tasmania were tragic for its fisheries and reflected no credit on the Government of the day. From his arrival in Tasmania to the end of 1886 he was in no doubt that his contract would be extended if he desired to stay but as the time approached he began to experience difficulty in getting the formal agreement. On 16 April 1887, he lodged another formal request for a new contract; when he had received no reply a month later he obtained leave to visit his brother Acland in Sandhurst (now Bendigo) in Victoria. Despite many members of the new Government being past supporters, E.N.C. Braddon being the most fervent and a key minister, the Government decided not to renew his contract (at least as a full-time position) and advised him by telegram whilst he was with his brother in Victoria. In editorials published on 2 and 7 June 1887, *The Mercury* called the decision "a serious mistake", warning that the government will "make a very grave mistake if they carry out their expressed intention"; it blamed the Salmon Commissioners and reminded readers of the Parliament's lack of support for them in 1886. "We are afraid the Ministers have been listening to a number of idle tales without taking the trouble to get the facts." The *Tasmanian News* was more definite in naming the Salmon Commissioners as the cause of Saville-Kent's trouble in the first of four editorials within three weeks on the subject published on 9 June:

> "It is well known that the Salmon Commission have always regarded with a feeling of disappointment and dislike the engagement under which Mr Saville-Kent came to the colony ... it is more than probable that the Salmon Commission have had something to do with the course of action regarding Mr Kent decided upon by the Government. We do not say that it is so. But if any want of cordiality exists, and it has become a question whether Mr Kent or the Salmon Commissioners are to be dispensed with, then there should be no hesitation about the matter. If the fisheries of the Colony are to be developed as they should be, then the department must undoubtedly have at its head a man of good scientific knowledge, and who can devote the whole of his time to the work. It cannot be expected that the Commissioners — some of whom occupy offices in the Civil Service, the duties connected with which must, or at least should, necessarily occupy their full attention — will be able to do this, and therefore to dispense with Mr Kent would be a very false step indeed. The Commissioners have rendered some excellent service to the Colony, and undoubtedly deserve a large amount of praise for the work they have done, but considerations of this kind must not be allowed to stand in the way of the efficient management of our Fisheries Department. The Commissioners paved the way for the department over which Mr. Kent was placed, and the continuation of the work they commenced may now very well be left in his hands. To do otherwise then retain the services of Mr. Kent — at least until Parliament expresses its will upon the question — in face of the very strong expression of opinion upon the subject that is being made, would be for Ministers to lay themselves open to a charge of acting from other motives than consideration for the proper management of a very important public department.
>
> "One only has to turn to the annual reports of the Superintendent of Fisheries to see that he is the right man in the right place; that his heart is in his work, and that if more work has not been done it has been through no fault of his own."

Saville-Kent's later time in Tasmania had been punctuated with clashes with some members of the Salmon Commission which at that time was desperately attempting to convince the world that it had succeeded in establishing the salmon *Salmo salar* in Tasmania. Although the Commission had been responsible for urging the appointment of an Inspector of Fisheries for Tasmania, it seems likely

that the members envisaged an inspector in the style of the rather eccentric naturalist Frank Buckland, who held the position of Inspector of Fisheries in Great Britain until 1881, not that of his successor, the much more scientific Thomas Henry Huxley. From his arrival in July 1884 Saville-Kent consistently rejected the claims that adult *S. salar* existed in Tasmanian waters. He established, and justified, that position in his first report in September 1884 and regularly confirmed it in three successive annual reports. The acclimatisation of salmonids has been widely studied over the past 100 years and this view has been confirmed together with the cause — the fish after leaving Tasmanian rivers for the ocean are unable to find their way back. Nevertheless, he continued to suggest methods that might lead to genuine success and finally suggested that other species of salmon, such as the quinnat or king salmon from North America, should be imported in place of *S. salar*. (Three years after he left Tasmania the Fisheries Board imported another American species — the rainbow trout. The introduction of the king salmon is again being considered today.)

It was unfortunate that the question of Saville-Kent's reappointment should have coincided with the death throes of the Agnew Government, although this and his advanced age do not absolve Dr William Agnew, widely acknowledged as one of the best informed men in Tasmania at that time, for his part in the loss of a most gifted scientist. This responsibility is shared with his successor as Premier, Phillip Fysh, who observed to the Royal Society

> "that their meetings were attended by scientific men, professional men and commercial men ... those connected with scientific pursuits were working with those engaged in professional pursuits. If science gave the commercial community any light as to the path of usefulness, commerce would surely follow."

If the Premier was praising the Society for bringing together young men from science, commerce and the professions to the benefit of the culture of Tasmania, as seems to be his intent, it does not seem entirely consistent with his decision five months earlier to dispense with one of the colony's new "men of science" because his work was "impractical". The Premier's desire to save money by cutting out scientific research related to fisheries did not inhibit him from offering a £500 government grant to the Royal Society sponsored scheme to foster scientific research in the Antarctic in the same year.

Perhaps the tragic events of 1860 should not be entirely dismissed as a possible factor in Saville-Kent's fall from influence. Despite the total absence of any reference to the crime during the time he was in Tasmania, the case was so prominent in England 20 years before it would not be surprising if someone in Tasmania made the connection. The Inspector had made enemies and the sister of the murdered child had come to Tasmania with William and Mary Ann. In addition he had made a trip to England the previous year and returned with Constance herself using the alias Ruth Emily Kay. Although Constance seems to have successfully hidden her identity during the remainder of her life, a mystery woman arriving from England might well have stimulated comment.

VICTORIA

After finishing his full-time appointment in Tasmania, Saville-Kent provided advice for the Victorian, Queensland and Western Australian Governments. After discussing future employment with the Victorian Government in Melbourne he returned to Hobart in June 1887 to complete his full-time employment at the end of September and commenced a two-month assignment in Melbourne in November. This was later extended for a further two months to complete a report on the potential fisheries of that colony.

Three Saville-Kent papers were tabled in the Victorian Parliament on 4 July 1888; the first was a report on the sponges of the Bahamas exhibited at the Fisheries Exposition in London five years before and is of little relevance. The other papers again reflected his far-sighted and practical approach to fisheries development, stressing the potential of oysters. He considered Westernport to have the potential as an oyster growing area to rival Arcachon in France. The local anchovy and pilchards were considered to have potential for canning — the latter as sardines. Artificial propagation and acclimatisation of indigenous freshwater fish and "desirable exotic species should also be examined".

The final report recommends a Fisheries Department with a skilled expert as director and urges the establishment of six government oyster farms (reserves) to "resuscitate and redevelop" the oyster industry. He stressed the need to import and demonstrate the new fishing techniques such as long lines, trammel nets and trawling and to introduce refrigerated rail cars to transport fish to

Melbourne. The second paper contains a long section, prompted by his uncertain position in Tasmania, in which he reviews the administration of fisheries in other Australian colonies and a number of countries, and the finance provided for their work (Saville-Kent 1888).

QUEENSLAND

Having spent two months back in Tasmania continuing his oyster work in March and April 1888, Saville-Kent returned to Melbourne and apparently participated in the Centennial Exhibition as a representative of E. P. Levy a furniture maker, although it is not clear why. In August he was invited to study the oyster beds in Moreton Bay, Queensland, and to join the surveying cruise of H.M.S. *Myrmidon* off northern Australia. Before leaving Brisbane he wrote to and later met the Premier Sir Thomas McIlwraith offering his services; the approach was favourably received and the Premier sought a detailed proposal. Leaving Brisbane on the *Tsinan* William travelled to Port Darwin where he joined the *Myrmidon* on 9 September. The cruise ended on 14 November when he rejoined the *Tsinan* for the trip back to Brisbane, observing and collecting specimens along the way.

He returned to Tasmania to finish his last report in January 1889. In February he was staying in Sydney, having been referred to the Premier Sir Henry Parkes by a mutual friend, the eminent painter, author, naturalist and critic, Louisa Anne Meredith who "hoped that his government would make better use of Kent's talents than its Tasmanian counterpart had done" (Ellis 1979: 210). Parkes did not take up the suggestion but Saville-Kent was asked to examine the oyster beds in the Georges River.

On leaving Tasmania he was immediately appointed Commissioner of Fisheries for Queensland where he remained until 1892. Taking up the position in March 1889 he embarked on an amazing programme of intensive work. By the end of April he had written his first report entitled "Food fishes of Queensland" (Saville-Kent 1890), a comprehensive assessment of all of the State's commercial species. In July he presented a report on Brisbane's fish supply, analysing the distribution system and reasons for high prices and poor quality. Within another month a report on the oyster fisheries of Moreton Bay was sent to the Treasurer. While in Moreton Bay he tested the set nets he brought from Tasmania and did some experimental trawling which revealed two valuable species of prawns. As the trawl was inefficient he ordered the newest design from England. Immediately that work was completed he went to Torres Strait at the special request of the Treasurer: it seems likely that his expertise in oyster culture was the reason for his appointment in Queensland. For two months he stayed at the Government Residence on Thursday Island, explored the main pearl shell grounds and studied the oysters. Contrary to the views of the industry he demonstrated that pearl oysters could be relaid to new beds and opened the way to resuscitate overfished areas. He wrote a preliminary report whilst at Thursday Island which reached Brisbane early in January 1890. On his return trip south he evaluated Cooktown, Port Douglas and Townsville as sites for oyster culture. In April 1890 he acceded to a request from the Chamber of Commerce of Maryborough and Bundaberg to survey the fisheries potential of Wide Bay. The report on Wide Bay finished, he set off again in April from Brisbane aboard H.M.S. *Rambler* for Thursday Island for the second stage of the pearl shell work. This time he stayed four months and extended his studies to the beche-de-mer. On returning to Brisbane, he delivered his Presidential Address to the Royal Society of Queensland (Saville-Kent 1891), the comments of members at the end of which attest to the regard in which he was held. In this address he strongly advocated the scientific approach to fisheries research and the desirability of establishing a marine research station: he urged that this facility should be established at Thursday Island. The next year he vigorously supported a university for Queensland before the Parliamentary Commission investigating the proposal. Whilst in Queensland from 1889 to 1891 he wrote five scientific papers and prepared four reports for the Colonial Treasurer.

His period in Queensland was crowned by the publication of his comprehensive and definitive book on the Great Barrier Reef published in 1893. The book was illustrated by excellent photographs, mainly stereoscopic pairs, which he took himself and 48 pages of paintings of fish, corals and other reef organisms. The *London Times* referred to it as "sumptuous" and *Nature* said it was "an edition *de luxe* ... nothing finer in the way of book illustration has come under our notice". A copy was presented to Queen Victoria by the author.

WESTERN AUSTRALIA

In December 1891 Saville-Kent resigned from the Council of the Royal Society of Queensland "to return to England". His contract with the Queensland Government completed, he revisited Hobart in January 1892 for the fourth meeting of the Australasian Association for the Advancement of Science where he presented a paper entitled "The marking of fish with relation to their ancestral or phylogenetic origin". The paper gave him the opportunity to again comment on the salmon acclimatisation debate.

William and Mary Ann returned to England in 1892 and took a house *Glenmore* in Chiswick Lane, Chiswick. He exhibited photographs, sketches and oysters at the Royal Society of London in June and worked on the Barrier Reef book which was finished in February 1893 and dedicated to the late Premier of Queensland, Sir Samuel Griffith.

The book was completed after he had gone to Western Australia to become Commissioner of Fisheries, where he stayed until March 1895. He commenced his work with a thorough review of the fisheries of Western Australia (Saville-Kent 1894a) in which he evaluated the edible fish, pearl oysters and exotics such as turtles and beche-de-mer. He was, of course, still particularly interested in edible oysters and in acclimatising "suitable freshwater fish for the rivers of Western Australia" (*ibid.*, Appendix 3). Following the methods he used in Tasmania he established an oyster breeding reserve at Albany along the same lines as those he started in Spring Bay, Tasmania, and later in Queensland (Saville-Kent 1894b). He then set about stocking the rivers of the southwestern part of the State with exotic species. He visited Tasmania, Victoria and South Australia in the summer of 1893–94 and returned on the *Cintra* via Adelaide, and Albany with specimens of Murray cod, Murray golden perch and the silver eel for release in the upper reaches of the Swan River in March 1894. At this time he was also contemplating the introduction of the Murray River crayfish (*Astacopsis serratus*) and the Tasmanian blackfish (*Gadopsis marmoratus*) together with salmon and trout. To prepare for the latter he built a hatchery at Bunbury similar to the facility at Plenty in Tasmania. The first brown trout ova arrived from Tasmania in August 1894 and were successfully reared and 600 young fish were released in each of seven rivers in the southwest in October.

About the beginning of 1890 Constance left Queensland for Melbourne and, during a typhoid crisis, began training as a nurse, a vocation begun in the convent 30 years before and continued in prison. On completing her training at the Alfred Hospital in Melbourne, Constance moved to Perth in August 1892 and was appointed matron of a private hospital. It is not clear whether she went to Western Australia first, and William followed, or vice versa. However, it seems likely that she was reluctant to return to England with William in early 1892 but, on hearing of his appointment to the post in Western Australia, she resigned from the Alfred Hospital to join him. In November 1893 they both returned to the east coast, she to join the Prince Henry Hospital in Sydney and he to spend a summer vacation in Victoria and Tasmania. During his vacation he was invited to stay in Hobart with Louisa Meredith. At this time she was 82 years old and living in Byron Street, Sandy Bay, in a cottage she called *Wren's Nest*. She was cared for by her grand-daughter also Louisa Anne Meredith, then 21 and a "high spirited girl capable of coping with her grandmother's domineering and demanding manner". Ellis (1979), relying on four pages of notes written later by the younger Louisa, recorded her "falling head over heels in love with a visiting scientist and dashed off to begin a new life with him in another state". Saville-Kent was the scientist and it seems they left for Western Australia where he had more than another year to serve to complete his contract. (The relationship appears to have been short-lived as she married a Mr Norville in Adelaide in December 1896.)

RETIREMENT

After his term as Commissioner in Western Australia, Saville-Kent returned to England in 1895 or 1896 to live at Chiswick and then moved to *The Rowans*, Wallington, Surrey in 1897. He spent a year writing another major monograph, *The Naturalist in Australia*, an illustrated book of some 290 pages, finished in February 1897 and dedicated to the Western Australian Premier, Sir John Forrest. Here his endeavour was to "present to the English reading public a few glimpses of the faunal and floral products of that magnificent component of our Empire — the Island-Continent of Australia". This book describes his discovery of corals and other tropical species around the Abrolhos Islands which led him to suggest the existence of a southward-flowing warm current. Some 80 years later, Australian oceanographers confirmed his perception with the discovery of the important Leeuwin Current which flows from the Timor Sea

down the coast of Western Australia and then westwards across the Great Australian Bight.

On 7 December of that year he addressed the Colonial Institute in London and delivered a paper entitled "Australian natural history gleanings" in which he supported Huxley's continental drift theory to explain similarities between the Australian fauna and flora and those of South Africa and South America. The next year he moved to *The Elms* in Elmwood Road, Croydon, but stayed there for only two years before moving back to the south coast where he had spent his childhood.

The last six years of his life were spent at *Bellisto*, in Milford-on-Sea near Lymington, Hampshire, but it is probable that he spent a good deal of the time between 1896 and 1907 in tropical Australia and adjacent areas engaged in pearl oyster culture. He provided additional advice to the Queensland Premier on the Torres Strait pearl oyster fishery in 1905 and presented a lecture to the Royal Society of Queensland in November of that year and again in 1907 on coral reefs. The report of the Royal Commission to Inquire into the Working of the Pearl Shell and Beche-de-Mer Industries, Western Australia, 1908 records that he "has shown his belief in the possibilities of cultivation [of oysters] by forming and undertaking the management of a company which is now engaged ... for 5 months ... in this work in Albany Pass near Somerset".

He died in Milford-on-Sea on 11 October 1908 of heart failure after an operation.

Constance remained in Australia, being in turn matron of Prince Henry Hospital, in charge of a leprosarium at Long Bay, and in 1898 matron of the Parramatta Industrial School for Girls where she remained until 1909. The latter appointment was ironic for a woman who had committed a gruesome murder at 16 years of age and who had spent 20 years in gaol. The publication of another book about her in 1929 (*The Case of Constance Kent* by John Rhode) prompted her to write an anonymous letter of 3000 words to the publisher putting her side of the story. She passed the last years of her life in Maitland and then Strathfield, New South Wales, working until she was 88 years old and determined to reach the century. On achieving that milestone and receiving laudatory messages from the King and the Governor-General, and being the subject of stories in the newspapers, she died two months later on 10 April 1944. Her picture in the newspaper no doubt reminded her of the last time such an event had occurred almost 80 years before during her trial but she kept her secret to the end, her death certificate confirming the fiction. Sadly there was no one to claim her remains which were buried in an unmarked grave in Rookwood Cemetery, Sydney.

To date there is no information on what became of William's half-brother Acland whom he visited in May 1887 when ill and living at Sandhurst, Victoria; nor of his half-sister Mary Amelia who accompanied him to Tasmania in 1884. Taylor reported that a sister was still alive in Australia when Constance died. Wiliam's elder sisters, Mary Ann and Elizabeth, lived together in East Hill, London, until Mary died in February 1913; her sister died in 1922. Both were buried in Putney Vale cemetary.

TRIBUTE

> "William's father and stepmother had always insisted that he would amount to nothing in his life. They were both so wrong." (Taylor 1979: 362).

Huxley's endorsement that he was a "distinguished scientist" was proved right (Thomas Brady to R. C. Read, Chairman of the Salmon Commission, 25 March 1884).

During his life Saville-Kent published three major books — *Manual on the Infusoria* (three volumes), *The Great Barrier Reef* and *The Naturalist in Australia*, over 40 scientific papers, and 19 major reports to four Australian governments. In a letter of 14 February 1919 to a Mr Smith-Woodward, apparently a friend of William and later Sir Arthur Smith-Woodward, distinguished palaeontologist, his elder sister Elizabeth stated that the style William Saville-Kent was his "nom-de-plume": if so, he began the practice very early in his writing career and also used the style officially during his period in Australia. He was a pioneer in the artificial culture of commercially valuable marine species and successfully cultured the European lobster, several species of oyster and numerous other species of Australian fish. In addition to his work in the marine field, he also described and brought to popular attention other animals principally from northern Australia. He was one of the great Victorian naturalists, writing in his lifetime papers on almost every group in the animal kingdom from Britain, Spain and Portugal, and Australia. A talented photographer, modeller and artist he brought to England a detailed picture of Australian nature: in *The Naturalist in Australia* he attempted

to cover land animals as well as marine animals. In addition to scientific observation and research he was committed to developing the fishing industry and, as well as offering advice to governments on this subject, he was prepared to go into business himself to foster his ideas on oyster culture. In a career extending from 1868 to 1908 he rarely stayed in any position very long; a three-year stop in one place seemed to be the maximum. Initially this may have been due to ambition and the desire for a better-paid post — note his dissatisfaction with his salary at the British Museum and when offered the position in Tasmania. Popular writing, initially with the *Popular Science Review*, may well have been helpful in supplementing his income. However, the scope of his writing and his continuous endeavours to establish a major English marine research facility suggest a restlessness and impatience which may well have demanded continuous challenge in a new environment.

He was the founder of Australian fisheries science and established a tradition of rigorous research in support of both the management of fish resources and the development of the fishing industry which was later to flower into internationally recognised fisheries departments in three states of Australia.

REFERENCES

BARBER, L., 1980: *THE HEYDAY OF NATURAL SCIENCE HISTORY, 1820–1870*. Jonathan Cape, London.

BERTRAM, J.G., 1873: *HARVEST OF THE SEA*. Third edition, John Murray, London,

ELLIS, V.R., 1979: *TIGRESS IN EXILE*. Blubber Head Press, Hobart.

SAVILLE-KENT, W., 1873: The Brighton aquarium. *Nature* 8: 531–533.

SAVILLE-KENT, W., 1883: The supposed coral eating habits of holothurians. *Nature* 27: 433.

SAVILLE-KENT, W., 1888: *Fisheries Reports*. Legislative Assembly, Victoria, 4 July 1888.

SAVILLE-KENT, W., 1890: *Votes and Proceedings of the Legislative Assembly of Queensland 1890*: 921–936.

SAVILLE-KENT, W., 1891: Presidential Address (1889–90). *Proc. R. Soc. Qld* 7(2): 17–42.

SAVILLE-KENT, W., 1894a: Fish and fisheries of Western Australia. In *Western Australia Yearbook 1893–4*.

SAVILLE-KENT, W., 1894b: *Report on Crown Lands Surveys*. Appendix 2. Lands and Surveys Department, Western Australia.

SUMNER, C.E., 1972: Oysters in Tasmania. *Tasm. Fish. Res.* 6(2): 1–15.

TAYLOR, B., 1979: *CRUELLY MURDERED*. Souvenir Press, London.

(accepted 28 April 1988)

APPENDIX

Bibliography

Books

1875: *OFFICIAL GUIDEBOOK TO THE MANCHESTER AQUARIUM*. Manchester.

1880, 1881, 1882: *A MANUAL OF THE INFUSORIA* (2 volumes and atlas). W.H. Allen, London.

1883: *HANDBOOK OF THE MARINE AND FRESHWATER FISHES OF THE BRITISH ISLANDS ETC*. Literature of the Great Fish Exhibition, 1: 73–204.

1893: *THE GREAT BARRIER REEF*. W.H. Allen, London.

1897: *THE NATURALIST IN AUSTRALIA*. Chapman & Hall, London.

1901: Marsupials and Monotremes. *In* Cornish C.J.*et al.* : *LIVING ANIMALS OF THE WORLD*. Volume I. Hutchinson, London: 344–384.

1901: Reptiles and Amphibians . *In* Cornish C.J. *et al. : LIVING ANIMALS OF THE WORLD. Volume I. Hutchinson, London: 344–384.*

1901: Shellfish, lampshells, sea urchins, starfishes, moss-animals, worms, corals, jellyfishes and sponges. *In* Cornish C.J. *et al.* : *LIVING ANIMALS OF THE WORLD*. Volume II. Hutchinson, London: 737–768.

Reports

9 Sep 1884: Superintendent & Inspector of Fisheries — Fisheries of Tasmania. *Parliamentary Papers 1884*. Hobart.

31 Jul 1885: Superintendent & Inspector of Fisheries — Annual report for 1884–5. *Parliamentary Papers 1885*. Hobart.

31 May 1886: Superintendent & Inspector of Fisheries — Annual report for 1885–6. *Parliamentary Papers 1886*. Hobart.

6 October 1886: Correspondence between the Salmon Commission and Chief Secretary re Saville-Kent. *Parliamentary Papers 1886*. Hobart.

31 May 1887: Inspector of Fisheries — Annual report for 1886–7. *Parliamentary Papers 1887*. Hobart.

31 May 1888: Inspector of Fisheries — Annual report for 1887–8. *Parliamentary Papers 1888*. Hobart.

31 December 1888: Inspector of Fisheries — Annual report for 1888. *Parliamentary Papers 1889*. Hobart.

1888: Commissioner of Fisheries — Fisheries report (vol. 1). Parliament of Victoria, Melbourne.

1889: Commissioner of Fisheries — Brisbane fish supply. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1889: Commissioner of Fisheries — Food fishes of Queensland. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1889: Commissioner of Fisheries — The oyster fisheries of Moreton Bay etc. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1889: Commissioner of Fisheries — Progress report on pearl-shell fisheries. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1890: Commissioner of Fisheries — Pearl and pearl-shell fisheries of northern Queensland. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1890: Commissioner of Fisheries — Fisheries, Wide Bay district. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1890: Commissioner of Fisheries — Beche-de-mer and pearl shell fisheries of northern Queensland. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1891: Commissioner of Fisheries — A Queensland University. The University Commission. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1892: Commissioner of Fisheries — Supplementary report on the food fishes of Queensland. *Votes and Proceedings of the Parliament of Queensland*. Brisbane.

1894: Commissioner of Fisheries — The establishment of an oyster breeding reserve at Albany (Appendix 2). *Lands and Surveys Dep. W.A.* Perth.

1894: Commissioner of Fisheries — The acclimatization of fresh-water fish (Appendix 3). *Lands & Surveys Dep. W.A.* Perth.

1894: Commissioner of Fisheries — Fish and fisheries of Western Australia. *W.A. Year Book 1893–4*. Registrar General W.A., Perth.

Scientific Papers

1870: On an existing coral closely allied to the Paleozoic genus *Favosites*, with remarks on the affinities to the Tabulata. *Proc. Zool. Soc. London*: 4 pp.

1870: Observations on the Madreporia or stony corals from the coast of Spain. *Proc. Zool. Soc. London*: 3 pp.

1870: On the Hexactinellidae or hexaradiate spiculed sponges taken in the "Norna" expedition off the coast of Spain and Portugal. *Mon. Microscop. J.* 4: 241–295.

1870: On a new anchoring sponge, *Dorvillia agariciformis*. *Mon. Microscop. J.* 4: 293–295.

1871: Affinities of the Sponges. *Nature* 4: 184–185.

1871: Zoological results of the 1879 dredging expedition of the yacht "Norna" off the coast of Spain and Portugal. *Nature* 4: 456–458.

1871: On a new genus of sponges from North Australia. *Proc. Zool. Soc. London*: 2 pp.

1871: On some new and little known madreporites in the British Museum collection. *Proc. Zool. Soc. London*: 275–286.

1872: Phosphorescence in fish. *Nature* 7: 47–48.

1873a: Intellect of porpoises. *Nature* 8: 229.

1873b: Fish distinguished by their action. *Nature* 8: 263–264.

1873c: The Brighton Aquarium. *Nature* 8: 531–533.

1874: Gigantic cuttlefish. *Pop. Sci. Rev.* 13: 113–127.
1875–6: Aquaria, their construction, management, and utility. *J. Soc. Arts* 24: 292–298.
1878: The origin and distribution of organic colour. *Nature* 18: 523–524.
1878: A new field for the microscope. *Pop. Sci. Rev.* 2: 113–132.
1881: Infusoria as parasites. *Pop. Sci. Rev.* 4: 293–309.
1881: The myxomycetes or mycetozoa; animals or plants? *Pop. Sci. Rev.* 5: 97–116.
1883a: The supposed coral eating habits of holothurians. *Nature* 27: 433.
1883b: On the artificial culture of Lobsters. *Literature of Gt Fish Exhibition*: 1–23.
1884: Notes on the infusorial parasites of the Tasmanian White Ant. *Pap. Proc. R. Soc. Tasm.* 1884: 272–273.
1886: Notes on the occurrence of the Sydney Crawfish on the coast of Tasmania. *Pap. Proc. R. Soc. Tasm.* 1886: 116–117.
1886: Observations on a suggested hybrid species of Tasmanian Trumpeter. *Pap. Proc. R. Soc. Tasm.* 1886: 117.
1887: Observations on the acclimitization of the salmon in Tasmania. *Pap. Proc. R. Soc. Tasm.* 1887: 52–66.
1887: Notes on the Tasmanian Butterfish. *Pap. Proc. R. Soc. Tasm.* 1887: 42–43.
1887: Notes on the identity of certain Tasmanian fish. *Pap. Proc. R. Soc. Tasm.* 1887: 47–48.
1889: Preliminary observation on a natural history collection made on the surveying cruise of HMS "Myrmidon". *Proc. R. Soc. Qld* 1889: 219–232.
1890: Notes on the embryology of the Australian rock oyster (*Ostrea glomerata*). *Proc. R. Soc. Qld* 7: 33–40.
1890: Presidential address. *Proc. R. Soc. Qld* 7 (2): 17–42.
1890: On the experimental cultivation of the mother-of-pearl shell. *Aust. Assoc. Adv. Sci* 2: 541–548.
1891: Notes on some new or little known Madreporaceae. *Rec. Aust. Mus.* 1: 123–124.
1891: Oysters and oyster culture in Australia. *Aust. Assoc. Adv. Sci.* 3: 559–561.
1891: Description of a new species of barramundi. *Proc. R. Soc. Qld* 8: 105.
1892: The markings of fish with relation to their ancestral or phylogenic origin. *Aust. Assoc. Adv. Sci.* 4: 381–386.
1896: The frilled lizard: *Chlamydosaurus kingi*. *Nature* 53: 395–398.
1897: Terra Australis Incognita. *Nat. Sci.* 11: 265–169.
1897: Australian natural history. *Nature* 56: 271–273.
1897: The market fishes and marine commercial products of Australia. *Scott. Geogr. Mag.* 13: 296–308.
1897–8: Australian natural history gleanings. *Proc. R. Col. Inst.* 29: 36–60.
1897–8: Remarkable termite mounds of Australia. *Nature* 57: 81–82.

Other

Letters to Sir Richard Owen 1873 and 1877, Owen Corres. Vol. XVI. British Museum of Natural History, London.
Letters to P.L. Sclater, 1869 to 1886. Zoological Society, London.
Letter to Royal Society of London, 4 May 1870. Royal Society, London.
Letter to Chief Secretary 29 August 1884, Hobart.
Letter to Chief Secretary Douglas, 26 May 1885, Hobart.
Letter to Chief Secretary, 4 June 1887, Hobart.
Letter to *The Mercury*, 16 June 1887 — re Mr Saville-Kent and the Salmon Commissioners.
Letter to Chief Secretary, 27 June 1887, Hobart.
Letter to Chief Secretary, 16 July 1887, Hobart.
Letter to Chief Secretary, 28 June 1888, Hobart.
Letter to *The Mercury*, 22 July 1887 — re The Superintendent and Inspector of Fisheries.
Letter to Chief Secretary, 30 July 1887, Hobart.
Letter to Chief Secretary, 6 August 1887, Hobart.
Letter to Edgar Smith, 30 July 1900, British Museum of Natural History, London.

THE D'ENTRECASTEAUX CHANNEL SCALLOP FISHERY: ITS PAST AND POSSIBLE FUTURE

by R. A. Perrin and R. L. Croome

(with two tables and six text-figures)

PERRIN, R.A. & CROOME, R.L., 1988 (31:x): The D'Entrecasteaux Channel scallop fishery: its past and possible future. *Pap. Proc. R. Soc. Tasm.* 122(2): 179–197. ISSN 0080–4703. Centre for Environmental Studies, University of Tasmania, Hobart, Tasmania.

The history of the D'Entrecasteaux Channel scallop fishery is discussed and its past and present structure and management are examined, with a view to providing a basis for future management. It has opened or closed over the years as production has fluctuated, closure being forced again in 1986 by evidence of overfishing and the sudden appearance of the toxic dinoflagellate alga *Gymnodinium catenatum* Graham. Lack of a comprehensive management plan impedes dealing with difficult administrative and biological problems or unexpected developments such as increased amateur participation or the present preponderance of the doughboy scallop (*Chlamys asperrimus* Lamarck) over the commercial scallop (*Pecten fumata* Tate). This is a serious obstacle to successful conservation and utilisation of the resource. Recommendations concerning the future of the fishery are made, in particular that the the fishery should be amateur-only while scallop stocks remain low.

Key Words: scallop, fishery, D'Entrecasteaux Channel, Tasmania, resource management.

INTRODUCTION

The D'Entrecasteaux Channel scallop fishery is of considerable importance to Tasmanians: it was at one time the third largest scallop fishery in the world (Anon. 1962) and has sustained many professional and part-time (amateur) fishermen over much of the last 60 years. Historically, the fishery has been plagued by recurrent collapses in production, resulting in closures of scallop beds for up to 12 years at a time. This paper details the history of the fishery and examines those aspects pertinent to its future.

THE CHANNEL AND ITS SCALLOPS

D'Entrecasteaux Channel, between Bruny Island and mainland Tasmania, runs SSW for approximately 45 km (fig. 1). Olsen (1955) divided the Channel into three areas based on topography and bathymetry: a deep open southern entrance with an average depth of about 40 m, an extensive shallow mid-section with an average depth of about 14 m, and a narrow northern channel with an average depth of 20 m.

It is a complex area hydrologically, with tidal, riverine and estuarine influences. The Derwent estuary to the north and the Huon River in the south can both have a major influence (Fairbridge 1953) and there is an increasing salinity gradient, from south to north, after heavy rain (Langlois & Cooper 1978). Water temperature ranges from 7 to 20°C (Fairbridge 1953).

Substratum types are highly variable, ranging from fine silt to coarse sand and rock (Olsen 1955, Sea Fisheries Division 1974, 1976). The northern section (Areas 1–5, fig. 1) has mostly a muddy bottom with sand fringes in the shallower areas. The mid-section (Areas 6–9) has mud, shell and rock substrata, and fine sand down to 20 m depth in Area 9. The southern section (Areas 10–12) is also variable, Areas 10 and 11 having sandy bottoms and Area 12 having a muddy bottom at depth and sand, rock and weed in its shallower parts.

Three species of scallops are present in the Channel, the queen scallop, *Equichlamys bifrons* Lamarck, the doughboy scallop, *Chlamys asperrimus* Lamarck, and the commercial scallop, *Pecten fumata* Tate. A survey by Olsen (1955) found commercial scallops to be most abundant along the edge of the Channel in its northern and southern reaches, and at 8–16 m depth in its mid-section. Present on any substratum, from silt-sand through to coarse sand and shale, the commercial scallops were often in beds or strips, 1–30 m or more in both length and width, with their long axes parallel to a flow or tide, or along contours in sheltered bays. The queen scallop was found to

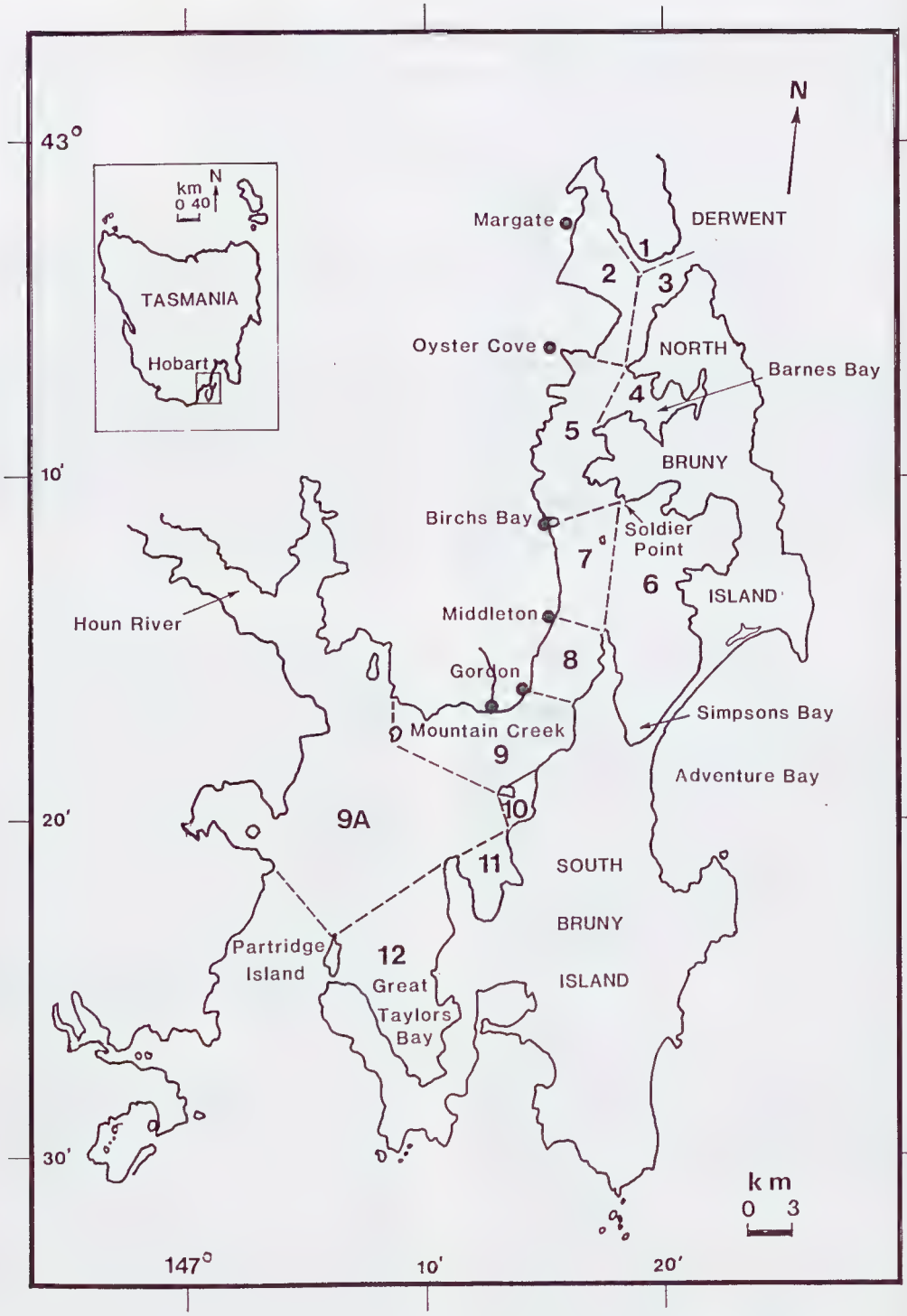

FIG. 1 — D'Entrecasteaux Channel showing designated scallop areas established in 1947 as part of an attempt to quantify catches and corresponding roughly with established scallop beds (Fairbridge 1953).

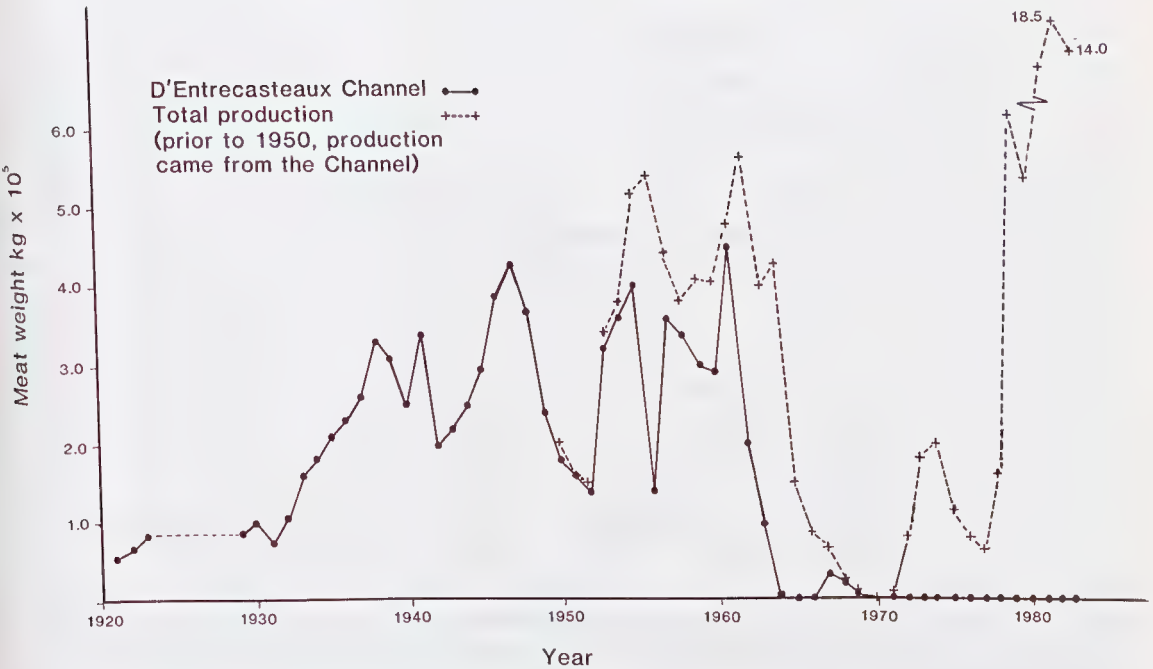

FIG. 2 — Tasmanian scallop production 1921–83. Data from Commissioners of Fisheries (1923), Fairbridge (1953), Anon. (1974) and TFDA (1982a, 1983).

occupy a shallower range throughout the Channel, from 2–14 m, often in association with rocky reefs and the seagrass *Zostera tasmanica* (Martens ex Aschers) den Hartog. The doughboy scallop had a similar depth range and horizontal distribution to the commercial scallop.

More recent surveys by the Tasmanian Department of Sea Fisheries (Harris 1981, 1982, 1983, Smith 1984, Zacharin 1985, 1986) have found that the commercial scallop is no longer abundant in the mid-section of the Channel, queen scallop numbers are also generally low, and the doughboy scallop is the most abundant species overall, particularly in Areas 5–8.

THE FISHERY TO 1982

As late as the 1880's scallops were not significant commercially in Tasmania, although the "commercial" scallop of today, *Pecten fumata*, was abundant in certain localities and was consumed locally (Seal *et al.* 1883). Significant numbers of scallops became available in the Hobart Market from 1905 (Anon. 1980). They were caught in the Derwent estuary in Rose Bay (Fairbridge 1953), Cornelian and Geilston Bays, near Lindisfarne and adjacent to the Domain (*The Mercury* 8 July 1910, p.6), and as far north as New Town Bay (E. Guiler, pers. comm.). However, depletion of the Derwent River beds soon forced fishermen downstream to Ralphs Bay (for doughboy scallops) and D'Entrecasteaux Channel (for commercial scallops) (Fairbridge 1953). The Ralphs Bay fishery was short-lived, closing in 1926, apparently due to restrictive legislation (Fairbridge 1953) and declining stock (Harrison 1965). Scallop fishing in D'Entrecasteaux Channel probably began around 1920 and continues to this day.

Figure 2 shows Tasmanian scallop production for the period 1921–83. Prior to 1950 the entire catch was from D'Entrecasteaux Channel. From the mid-1950's to the late 1960's a significant proportion of the catch was taken from beds off the east coast, and from the early 1970's the Bass Strait beds provided the harvest (see also Perrin & Hay 1987). Boat numbers and length of the scallop season for D'Entrecasteaux Channel for the period 1933–63 are shown in figure 3. Figure 4 shows an approximate measure of catch per unit effort over the same period (annual catch ÷ (number of boats x season length in months) = catch per boat-month). Figure 5 shows meat weight/1000 scallops and scallop prices.

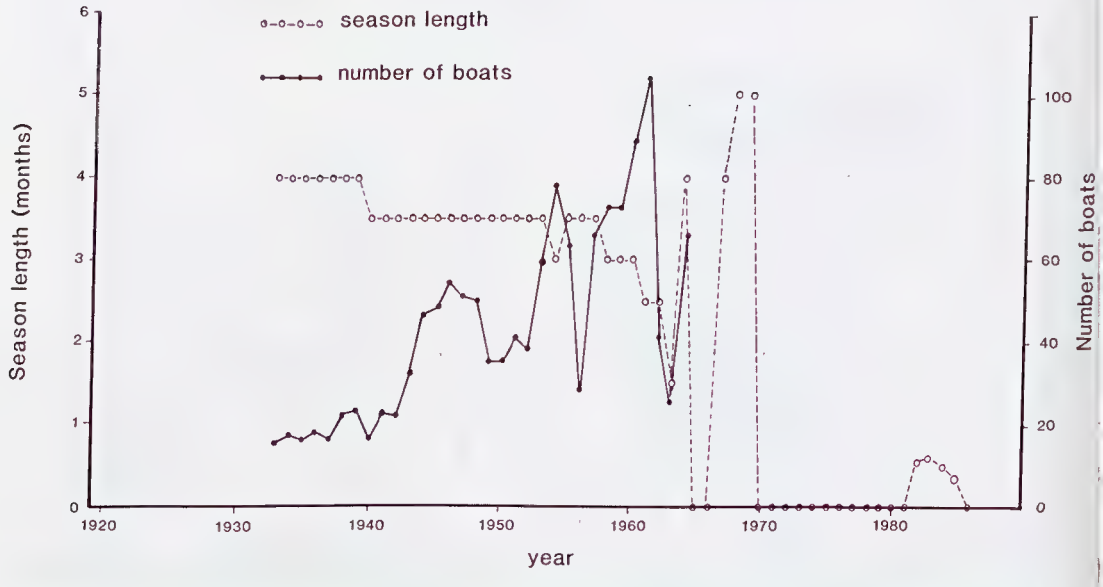

FIG. 3 — Boat numbers and scallop season length for D'Entrecasteaux Channel. Data from SFABT Subcommittee (1964) and an unpublished report of the Council for Scientific and Industrial Research, Fisheries Division (Anon. 1947).

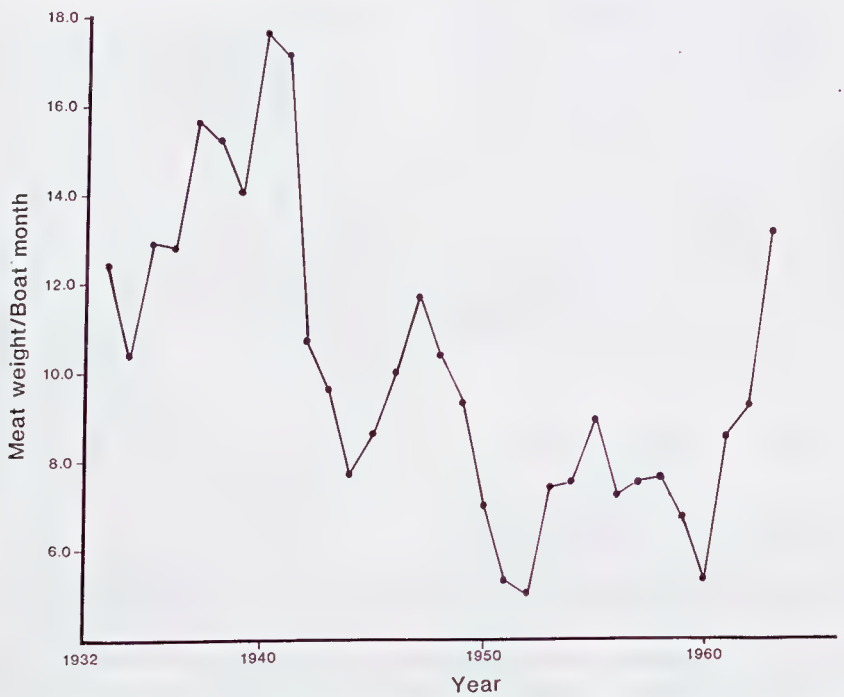

FIG. 4 — Approximate catch per unit effort for the D'Entrecasteaux Channel scallop fishery (see text).

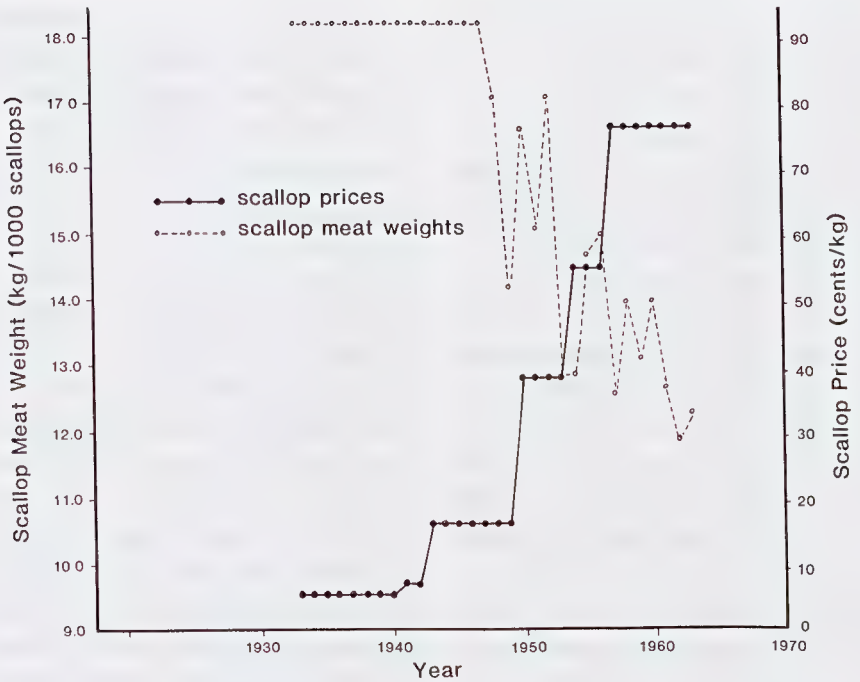

FIG. 5 — Scallop prices and scallop meat weights for D'Entrecasteaux Channel, 1933–63.

The fishery was carefully fostered from its early days. The beds were monitored for signs of overdredging (Sea Fisheries Board Tasmania (SFBT) 1933) and the northern parts of the Channel were closed for this reason in 1925–26 and 1930–31 (Select Committee of the Legislative Council (SCLC) 1960, SFBT 1930). The splitting of scallops at sea was also prohibited, due to the numbers of starfish attracted by the shells and adhering viscera (Anon. 1947).

The commercial scallop formed the bulk of the catch in the early 1920's (Fairbridge 1953) but during the late 1920's and 1930's the doughboy scallop became the most important constituent of the catch (SFBT 1933). This change in species catch was probably due to the commercial scallop becoming rare in the Channel at this time (Harrison 1965) possibly due to starfish predation (Anon. 1947). By 1938, however, 85% of scallops being caught were again commercial scallops (SFBT 1938, *The Mercury* 17 August 1940, p.4).

Total scallop production increased from 153 000 kg meat in 1933 to 327 000 kg in 1938 (fig. 2) but the number of boats fishing for scallops did not increase markedly, remaining at about 20 (fig. 3), and it is likely that the rise in catch per unit effort during this period (fig. 4) was due to the mechanisation of dredge-hauling.

In 1934 the legal minimum size for commercial scallops was increased from 3.5 inches (88 mm) at its widest diameter to 3.5 inches at its smallest diameter (Anon. 1947), while that for the doughboy scallop remained at its 1925 limit of 2.75 inches (69 mm) at its smallest diameter (Fairbridge 1953). In 1935 the width of scallop dredges was limited to four feet (1.3 m) to protect the scallops from being crushed by the weight of the net being dragged over the bottom (Anon. 1947). The meat weight per thousand scallops was stable around 40 lbs (18.2 kg) per 1000 scallops, an indication that there was no trend towards smaller scallops, as would be expected if recruitment overfishing was occurring (Sea Fisheries Advisory Board of Tasmania (SFABT) Subcommittee on the Scallop Fishery 1964).

From 1938–42 there were fluctuations in the catch and the catch per boat month, indicating that the fishery may have removed much of the accumulated stocks of scallops and that fishing was now relying on annual recruitment (Harrison 1965). It is also likely that the catch was adversely affected by enlistments in the Australian Imperial

Forces: in 1939 there were 27 boats with 74 men working 52 dredges but in 1940 there were 20 boats with 45 men working 42 dredges (*The Mercury* 31 May 1940, p.4).

Concern about the possible depletion of the scallop beds led to biological investigations on growth rates, migration, and the effect of fishing pressure (Tubb 1946). Tubb's work concentrated on scallop tagging experiments and he concluded that analysis of tag returns, together with the collection of fisheries catch data, could form the basis for an assessment of the effects of fishing on the scallop stocks.

From 1942 to 1947 scallop production increased, as did the number of boats. Harrison (1965) suggested the increase in production was due to four factors: an increase in the number of dredges carried by each boat, the change from doughboy to commercial scallops as the major species being caught, the development of the southern areas of the Channel for scallop fishing, and a good spawning of scallops in 1937–40.

From 1947–52 total scallop production fell. The number of boats also fell, from 51 in 1947 to 38 in 1952. Meat weights per 1000 scallops began to fall after 1947; it is likely that the accumulated stocks of legal-size commercial scallops were steadily reduced from 1942–46 and that after 1947 the size of the catch was more directly related to recruitment (SFABT Subcommittee 1964). A limit of two dredges per boat was enforced in 1949 (Department of Agriculture (D.A.) 1949).

The rapid decrease in production from 1947–52 resulted in speculation on the future of the Tasmanian scallop fishery, and fishermen were forced further afield into Norfolk Bay, Coles Bay, and other areas on the east coast. Concern about the future of the D'Entrecasteaux Channel beds led to a transplantation of 90 000 two- to three-year-old scallops from the east coast to Area 2 (fig. 1) (Harrison 1965, D.A. 1953).

A biological assessment of the Channel fishery was made by Olsen (1955) who found that "the successful spatfall and subsequent development of a strong year class is very sporadic and as yet, unpredictable". He found that there had been a heavy spatfall in about 1940 and another one in 1948, and it seemed the productive potential of the Channel's scallop stocks fluctuated around the success or otherwise of these spatfalls, if about six years was allowed for the scallops to enter the fishery (SFABT Subcommittee 1964).

The period 1952–55 saw a rapid increase in scallop catch, boat numbers, and catch per boat month (figs 2, 3, 4) but scallop meat weights began to decrease (fig. 5). The findings of Olsen (1955) suggested that the 1948 year class had entered the fishery and was providing the bulk of the catch. In 1956 the Channel fishery catch dropped sharply, and was only 27% of the total Tasmanian catch. The fall was due largely to a transfer of fishing effort to Norfolk Bay. However, the Norfolk Bay beds did not produce many scallops in 1957 and by 1959 the catches there had decreased to very low levels (Harrison 1965).

From 1956–61 scallop catches increased again in the Channel and in 1961 the peak catch of 454 000 kg meat was taken. Boat numbers steadily increased to a record 104 in 1961 but catch per boat month remained low. It seems that the high production level was achieved by increased fishing effort, and the low catch per boat month and decreasing meat returns per 1000 scallops suggest that the Channel scallop stock was being overfished. The season was shortened from 14 weeks in 1956 to 10 weeks in 1961.

One controversial alteration to fishing technique at this time was the introduction in 1958 of an English scallop dredge; the "Baird" or "Sputnik" dredge. The majority of Channel fishermen believed this new dredge destroyed more scallops than the established lip dredge (Langford 1959) but because the dredge was more efficient in deeper water and on hard substrates, many used it (*The Mercury* 12 June 1959, p.4). In 1958 the Licensed Fishermen's Association submitted a resolution to the Sea Fisheries Advisory Board asking that the dredge be banned from the Channel. This was accepted by the Board (SFABT 1959) but "Sputniks" were not banned from the Channel until the 1962 scallop season.

Concern over the scallop industry's future, prompted by the controversy surrounding the "Sputnik" dredge, resulted in the appointment in 1960, of a Select Committee of the Legislative Council to enquire into the scallop fishery of Tasmania. The Committee received submissions from 45 fishermen and took into account CSIRO research on scallop dredge efficiency before concluding that spiked dredges, such as the "Sputnik", caused considerably more damage to the scallops than did the lip dredge. The Committee recommended the banning of all spiked dredges from the Channel, subject only to further investigations by the CSIRO (SCLC 1961).

Harrison (1965) believed the controversy surrounding the "Sputnik" dredge helped to confuse the issue of why scallop stocks in the Channel were at such low levels and that factors such as the rising price of scallops (fig. 5) and the

shift in exploitation focus to new beds around the state also obscured the decrease in catch per unit effort, the usual indicator of overfishing.

The Channel scallop catch fell dramatically from 1961–64. This slump again forced some southern Tasmanian fishermen to look elsewhere for scallops, including Port Phillip Bay in Victoria, and also resulted in the appointment of a sub-committee by the Sea Fisheries Advisory Board to give advice on the opening date and duration of the 1964 scallop season and on the scallop fishing operation in general. The Committee reviewed the history of the Channel fishery, commented on the regulations in force, and recommended that the scallop season in the Channel be open for six months in 1964, from 15 May to 15 November (SFABT Subcommittee 1964). However, the fishery was opened for four months only, from May to August.

The arguments the Committee put forward for a six-month season are worth examining in the light of later events. The Committee stated that the basis of the two- to three-month season was that scallop flesh weight fluctuated during the year and the season was set to maximise yield per scallop. It argued, however, that the season brings little advantage by way of increased harvested meat, contending that weight loss due to year round harvesting would not exceed 27%. The Committee then listed the disadvantages of a short season, including the concentration of fishing effort resulting in inefficient use of equipment and labour, little regard for size regulations, and inefficiencies of splitting scallops. It concluded that the limited season made no contribution towards limiting catch or effort, and favoured a management policy which amongst other things placed no restriction on the time of fishing, with the provision that if fishing effort continued to the point where recruitment was endangered then the season should be closed (SFABT Subcommittee 1964).

Scallops are recorded as being taken from the Channel during only three months (May–July) in 1964 (DA 1965) and it seems they were rare and in poor condition (*The Mercury* 15 May 1964, p.2). The season was closed in 1965 and 1966. Scallop sampling undertaken every three months in 1965 revealed no signs of recovery of commercial scallop numbers, though doughboy scallops were plentiful in some places (Harrison 1966).

A survey in 1967, undertaken by officers of the Sea Fisheries Division, found that the commercial scallop numbers in the Channel were low but considerable recruitment of doughboy scallops had occurred due to spawning in 1962, 1963 and 1964 (Anon. 1967). The season was opened in 1967, from August to November, and eight boats took 35 000 kg of scallop meat.

In 1968 the Channel produced 24 000 kg of scallop meat and in 1969, just 6800 kg. The 1969 survey of the Channel showed that doughboy scallops were rare and the only juveniles present were those of the queen scallop (DA 1970).

Speculation on the causes of the major collapse (after 1961) included changes in the marine environment brought about by natural processes and industrialisation (Harrison 1975), changes in the hydrological condition of the area which precluded commercial scallop settlement (Anon. 1967), and pollution from insecticide sprays used in orchards (*The Mercury* 13 June 1969). It also seems likely that the extra long seasons of 1964, 1967, 1968 and 1969 (fig. 3), the disguised fall in catch per unit effort (Harrison 1965), and the introduction of the "Sputnik" dredge were contributing factors to this collapse.

For the next 12 years (1970–81) the Channel scallop fishery was closed in an attempt to rebuild scallop numbers. Annual surveys of the scallop beds continued. The 1970 survey revealed small concentrations of doughboy scallops, while queen and commercial scallops were scarce (DA 1971). This was the pattern for the next eight years, that is, an annual survey of the Channel beds and a report of few scallops. In 1979 and 1980 no surveys were done but in 1981 a survey revealed quantities of doughboy scallops in Great Bay and Simpsons Bay (fig. 1). At this stage fishermen pressed for a limited opening of the area and a more comprehensive survey was undertaken to evaluate this possibility. The second survey found that while there was a good settlement of doughboy scallops, commercial scallops numbers were still low. The recommendations were made that the Channel be closed in 1981 but that another survey be undertaken in 1982 with a view to opening the beds (Harris 1981). In 1982 a joint government/industry body, the Scallop Industry Liaison Committee, recommended a short open season be allowed in Area 6, and this is taken to be the commencement of the current fishery.

THE CURRENT FISHERY, FROM 1982

Since 1965, and probably earlier, the Department of Sea Fisheries (formerly the Sea Fisheries Division and then the Tasmanian Fisheries Development Authority (TFDA)) has conducted regular surveys of the Channel scallop

beds to assess the distribution, age, and size structure of the populations of doughboy, queen, and commercial scallops, and to determine the effects of the fishing of previous years on the scallop stock. The annual survey is carried out prior to any decision on the current year's scallop season. From 1970–78 few scallops were found and the beds remained closed.

In 1981 there was considerable pressure from fishermen to open Area 6 (fig. 1) due to the apparent presence of significant quantities of doughboy scallops in the area. A dredging survey was made using a 2.45 m mud dredge, and a similar survey has been conducted each year since, The results of these surveys are collated in table 1, and a summary of the Channel fishery statistics from 1982 to 1985 is given in table 2.

The 1981 survey was conducted between 12 and 14 May and showed that, while there were large numbers of doughboy scallops in Area 6, most were undersize; no season was allowed.

The 1982 survey was limited to Areas 6, 7 and 8, and once again showed the presence of large numbers of doughboy scallops, most of which had reached takable size. The Scallop Industry Liaison Committee recommended that there be a short open season with fishing limited to Area 6 (Harris 1982). Around 180 boats fished on the first day of the 17-day season (3–19 July). All three species of scallop could be taken, and there was no bag limit except for divers. Most amateur fishermen reported good catches, and some of the professional boats in the fishery were taking up to 30 bags in a seven-hour period (*The Mercury* 6 July 1982). There were complaints from some amateur divers that their bag limit of 200 scallops per day was too low, especially when there was no bag limit for other amateur or professional fishermen (TFDA 1982b). Fisheries inspectors reported a successful season from an enforcement viewpoint (TFDA 1983), but isolated incidents of scallop dumping were alleged, apparently due to excessive catches (*The Mercury* 5 August 1982).

The 1983 survey was conducted from 18 to 20 April and concentrated on Areas 6, 7 and 8. It showed virtually no change in the distribution of scallops but a slight increase in the abundance of doughboy scallops. Dredge tows undertaken in other parts of the Channel revealed no significant concentrations of scallops. The slight increase in

TABLE 1
Results of D'Entrecasteaux Channel scallop Surveys 1981–86*

Area**	1981			1982			1983			1984			1985			1986		
	D	C	Q	D	C	Q	D	C	Q	D	C	Q	D	C	Q	D	C	Q
1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	2	0	0	–	–	–	49	0.33	0	91	1.7	0.7
3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	60	5.0	15
4	–	–	–	–	–	–	–	–	–	–	–	–	1.5	1.5	0	–	–	–
5	–	–	–	–	–	–	0	0	0	143	0.75	0	7.6	3.0	0	216	3.7	0.8
6	545	1	–	234	1	–	296	1		291	1.3	0.8	144	3.7	2.2	188	10.5	2.6
7	29	3	–	71	5	–	91	8		130	4.4	19.1	55	7.2	18.6	99.5	6.7	15.5
8	256	4	–	60	7	–	73	6		44	5.2	7.4	46	3.1	5.1	91	6.1	8.6
9	–	–	–	–	–	–	2.8	1.6	0	10	1.0	0	55.8	2.9	0.6	117	3.9	5.1
9A	–	–	–	–	–	–	0.3	0	0	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	0	96	0	7.0	124.6	0.5	7.2	59	2.0	5.0
11	–	–	–	–	–	–	10	0.7	0	115	0.6	3.5	227	1.6	7.4	45	7.3	7.9
12	–	–	–	–	–	–	0.2	0.8	0	4	0.2	3.6	0.33	3.3	0	1	10.8	0.1

* Numbers in table represent average catch per five-minute haul of a 2.4 m mud dredge with teeth. Dashes represent no survey being undertaken.
** Scallop areas (fig. 2).
D = doughboy; C = commercial; Q = queen.

doughboy scallop numbers from the 1982 to the 1983 survey resulted in a recommendation of a longer season of 4 to 6 weeks for the 1983 season, again restricted to Area 6 only (Harris 1983). Prior to the opening of the season, the Minister for Sea Fisheries announced tighter controls on fishing effort, such as the introduction of bag limits, which were designed to discourage the participation of large scallop fishing vessels (Media Release from Minister for Sea Fisheries, R. J. Beswick, 20 June 1983). Opening day (2 July) saw about 200 boats fishing in Area 6 (*The Mercury* 4 July 1983, p.3) for all three species of scallop (Anon. 1983). After some ten days, declining catch rates became obvious and forced a recommendation from the Minister for Sea Fisheries that the Channel should close early, on 20 July, on the grounds of excessive catches and the desire to leave some scallops for future breeding (Media Release from Minister for Sea Fisheries, I. M. Braid, 14 July 1983).

The 1984 survey was conducted from 9–11 April. Once again doughboy scallop numbers were greatest in Area 6, while commercial and queen scallops were most abundant in Areas 7 and 8. The number of doughboy scallops had not decreased in Area 6, even though there had been two fishing seasons in this area. The recommendations arising from this survey were that Area 6 be opened again, but Areas 7 and 8 should remain closed to protect the breeding stock of commercial and queen scallops (Smith 1984). A further reduction in bag limits was enforced, and a ban placed on the taking of commercial scallops. The 16-day season began on 7 July, and around 600 boats packed Simpsons Bay (Area 6), 500 of them with amateur licences (Anon. 1984).

The 1985 survey was conducted from 29 April–1 May and examined most areas of the Channel. Doughboy scallop numbers in Areas 6 and 7 had decreased markedly. The decrease in Area 6 was attributed to heavy fishing pressure during the 1984 season but no reason could be given for the decrease in Area 7 (Zacharin 1985). As the 1985 survey catch in Area 6 was less than 50% of the 1984 survey catch, and as there were many juvenile doughboy and commercial scallops present, it was recommended that Area 6 remain closed during 1985. Instead, Areas 8, 9, 10 and 11 were opened for a limited season from 6–15 July, with bag limits further reduced. Opening day again saw 600 boats or more in the Channel but total catch and catch rates were low, some boats returning without any catch (Anon. 1985a). This is surprising as the pre-season survey suggested high numbers of doughboy scallops in Area 11 in particular.

The 1986 survey was conducted from 28–30 April. It showed that Areas 5, 6 and 9 had the highest numbers of doughboy scallops, Area 7 had the highest numbers of queen scallops, and commercial scallops were increasing in abundance in a few areas of the Channel. The recommendations from this survey were that Areas 5 and 7 be opened for a nine-day season if the licensing arrangements for amateurs were changed from one licence per boat to one licence per person, and if commercial vessel numbers were severely restricted (Zacharin 1986). The Minister for Sea Fisheries approved arrangements to create a special

TABLE 2
D'Entrecasteaux Channel Scallop Fishery Statistics 1982–85

Year	Season	Area fished	Licences issued		Daily catch limits		Catch* (kg meat)	Catch per unit effort (kg meat/dredge hr)
			Amateur	Professional	Amateur	Professional		
1982	3–19 July	6	375	12	none**	none	2302	30.5
1983	2–20 July	6	667	70	1000	15000	32585	14.1
1984	7–22 July	6	751	104	400	8000	40451	7.7
1985	6–15 July	8	734	87	400	6000	663	2.4
1985	6–15 July	9					1360	2.6
1985	6–15 July	10					58	1.9
1985	6–15 July	11					64	1.3

* Catch and catch per unit effort are for professional fishermen only.
** In 1982, amateur divers were limited to 200 scallops per day.

licence for professional fishermen wishing to fish in the Channel, and in Storm and Norfolk bays. However, the 1986 Channel fishery did not eventuate, due to two factors: the sudden appearance of a planktonic toxic dinoflagellate in parts of the Channel, resulting in some scallops becoming contaminated to dangerous levels, and a desire on the part of management to rest the scallop beds (*The Mercury* 24 July 1986).

From the data in table 2, it is apparent that the Channel scallop beds are suffering from overexploitation. This is occurring despite the reductions in season length and bag limits introduced to control the rapid increase in fishing effort. The professional catch was relatively small in 1982, rapidly expanded in 1983 and 1984, but collapsed in 1985, and since 1982 the catch per unit effort for professional fishermen has fallen dramatically, making it economically non-viable for many to fish in the Channel (G. Innes, pers. comm.).

The modern fishery also has a very large amateur component: in 1985 some 730 amateur licences were issued, against 87 professional licences being endorsed for the Channel. Catch and catch per unit effort figures are not available for the amateur component of the fishery, but taking the 1985 professional/amateur licence numbers and catch limits, if all fishermen took their daily quota, then amateur fishermen would have caught about half as many scallops as the professionals.

MANAGEMENT

Management of the D'Entrecasteaux Channel scallop fishery is largely the responsibility of the Department of Sea Fisheries, with participation also by the Police Marine Division and the Marine Board of Hobart. The Department of Sea Fisheries conducts annual scallop surveys, issues licences to harvest the resource, liaises with fishermen and conducts a limited research program in the Channel. The Police Marine Division and the Marine Board of Hobart are responsible for enforcing the Sea Fisheries Regulations and the Port of Hobart Regulations respectively.

Other interested parties also have a management input, as is illustrated by the decision-making process for the opening of the Channel to scalloping (fig. 6). Following the scallop survey the Assistant Director (Management) calls a meeting or

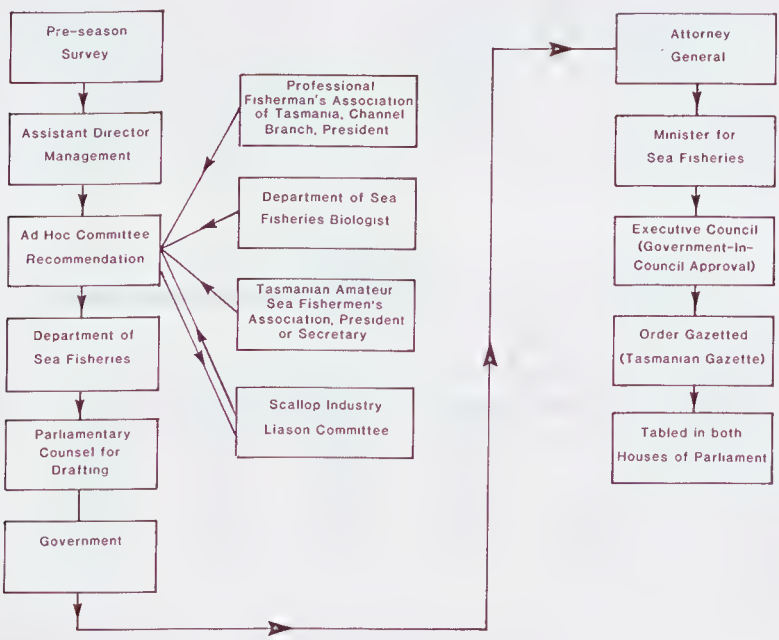
Pre-season Survey
Assistant Director Management
Ad Hoc Committee Recommendation
Department of Sea Fisheries
Parliamentary Counsel for Drafting
Government
Professional Fisherman's Association of Tasmania, Channel Branch, President
Department of Sea Fisheries Biologist
Tasmanian Amateur Sea Fishermen's Association, President or Secretary
Scallop Industry Liason Committee
Attorney General
Minister for Sea Fisheries
Executive Council (Government-In-Council Approval)
Order Gazetted (Tasmanian Gazette)
Tabled in both Houses of Parliament

FIG. 6 — Decision-making process for the D'Entrecasteaux Channel scallop fishery.

contacts individually the President of the Channel Branch of the Professional Fishermen's Association of Tasmania (PFAT), the President or Secretary of the Tasmanian Amateur Sea Fishermen's Association (TASFA), and a biologist from the Department's research laboratories at Taroona. Recommendations on season length, bag limits, licence costs, areas of opening, and participation by amateur and professional fishermen are made at this meeting (J. Thomson, pers. comm.). The Scallop Industry Liaison Committee is informed of the meeting's recommendations and asked for comment. The recommendations are sent to the Director of Sea Fisheries: a Scallop Seasons Order is drafted and tabled in both houses of Parliament.

At present there is no formal written management policy for the D'Entrecasteaux Channel scallop fishery (J. Thomson, pers. comm.). However, the 1985 Channel survey report suggested that the prime management objectives of the Department of Sea Fisheries (DSF) concerning the scallop fishery in D'Entrecasteaux Channel were as follows (Zacharin 1985):

> "to build up the populations of commercial scallops throughout the Channel and the protection of juvenile scallops, and to ensure the continuation of a limited annual fishing season for doughboy and queen scallops."

Research in D'Entrecasteaux Channel by the Department of Sea Fisheries officers has concentrated on commercial scallop growth rates, re-seeding, and aquaculture potential. A number of scallops have been tagged and released to obtain growth rates and ring formation data for comparison with similar experiments elsewhere in Tasmania. A re-seeding trial has recently been carried out in one area of the Channel (results of the experiment are not yet available) and investigations have been made on spat settlement. An examination has also been made of the possibility of scallop aquaculture using a cage culture technique, but with little success due to poor growth rates and uneconomical methods of on-growing scallops (D. Cropp, pers. comm.).

Enforcement of the Sea Fisheries Regulations pertaining to scallops is undertaken by officers of the Police Marine Division. Under normal circumstances, the Marine Division maintains a "watching brief" on the D'Entrecasteaux Channel scallop fishery, that is, surveillance patrols made to the west coast of Tasmania or to southern Bruny Island also inspect D'Entrecasteaux Channel. About three weeks prior to the opening of the Channel, two boats make patrols of the Channel on a regular basis, and occasional night patrols are also made.

During the scallop season two or three boats are used to patrol the fishery. One boat (of 16 m with radar) is used as a mobile base and conducts night patrols (as daylight fishing only is permitted in the Channel), the others (faster runabouts) are used for inspectorial duties. Marine Division officers check on bag limits, gear, licences and evidence of shucking scallops, ensure that all fishing is within the prescribed scallop areas, and help to collate information on scallop catch rates.

According to the Divisional Inspector (Marine Division of the Police Department), amateur and professional fishermen transgress the regulations at about the same rate (R. Massie, pers. comm.). Taken overall, the Channel has been free of many enforcement problems, and amateur and professional fishermen have usually co-operated with police (TFDA 1983, 1984).

With regard to the operations of boats, professional and amateur fishermen come under the jurisdiction of both the Marine Board of Hobart and the Navigation and Survey Authority. The enabling Act is the *Marine Act* 1976 which, as amended, stipulates many practices with which fishermen must comply.

MANAGEMENT PROBLEMS

The situation faced by the managers of the D'Entrecasteaux Channel scallop fishery, management of a living marine resource with variable fecundity, high palatability and within easy reach of amateur and commercial fishermen, can hardly be considered easy and presents both biological and management problems.

Biological Problems

Variability of Recruitment

Annual recruitment to the fishery varies through variability in spatfall and consequent fluctuation in scallop production, as has been reported from scallop fisheries in Australia and throughout the world (e.g. Serchuk *et al.* 1979, Gwyther & Sause 1985). Olsen (1955) considered its importance for the scallop fishery of D'Entrecasteaux Channel, and found that the Channel fishery depended on occasional heavy spat settlement, which might sustain the fishery for up to nine years. He speculated that the successful settlement of spat was dependent on a delicate

balance of environmental variables; others have proposed specific biological and physical variables as controlling factors, including food availability (Franklin *et al.* 1980), water temperature (Dow 1962 *in* Serchuk & Rak 1983), and wind, current, and rainfall (Campbell 1984).

Attempts have been made to minimise the adverse effects of variable spatfall and recruitment. The management of many scallop fisheries relies heavily on pre-season spat collection programmes and/or dive surveys over scallop beds, such as in the Port Phillip Bay scallop fishery (Gwyther & Sause 1985) and the United Kingdom scallop fishery (Franklin et al. 1980). Pre-season dredge surveys over scallop beds, similar to those made in D'Entrecasteaux Channel, are also undertaken in the U.S.A. and Canada (Serchuk *et al.* 1979).

In Japan the routine production of scallop spat for re-seeding or aquaculture has resulted in a ten-fold increase in the total scallop catch, and in the U.S.A. and France it has increased production and helped stabilise the scallop industries (Miller *et al.*, *in* Campbell 1984). In Golden Bay (New Zealand) re-seeded areas are now increasing the availability of scallops for fishermen and consumers (Anon. 1986b).

In Tasmania spat forecasting has been tried but proved unsuccessful, while dredge surveys are used routinely prior to the opening of the D'Entrecasteaux Channel scallop season. Recent success with the production of hatchery-reared scallop spat (Anon. 1986a) suggests that improvements in total catch and an increasing degree of industry stability (via scallop aquaculture and re-seeding) may be feasible in the D'Entrecasteaux Channel scallop fishery in the near future.

Toxins

The second biological problem is the presence of toxic dinoflagellates. Dinoflagellates are planktonic unicellular algae and are part of the food chain for many marine organisms. Some dinoflagellate species produce potent neurological toxins, and these may be accumulated in filter-feeding organisms such as oysters, mussels and scallops, posing a threat to humans who eat these molluscs. Of the 1500 or so known dinoflagellates, only 20 are known to produce paralytic poisons (Hallegraeff & Sumner 1986) but problems with these toxic dinoflagellates are world-wide (Yentsch 1984).

In 1986 there was no Channel scallop season, partially due to the presence of high numbers (a "bloom") of the toxic dinoflagellate *Gymnodinium catenatum* Graham in various parts of the Channel, and high levels of toxins in oysters, mussels and scallops from these areas (Oshima *et al* 1987). This discovery resulted in the temporary closure of 14 aquaculture farms growing oysters and mussels in the Port Cygnet and lower Huon River area (Hallegraeff & Sumner 1986).

A monitoring programme was instigated to test for the dinoflagellates in the water column and toxins in the shellfish. Samples of scallops from the D'Entrecasteaux Channel were tested at the Institute of Medical and Veterinary Science in Adelaide and found to contain high toxin concentrations in the flesh and gonad, and low concentrations in the adductor muscle (DSF 1986).

The high populations of *Gymnodinium catenatum* may have been due to the heavy summer rains in 1986, which lowered salinities in inshore regions (which apparent favours some dinoflagellates), increased organic and inorganic runoff from agricultural land, and stabilised the water column due to freshwater inflows (*The Mercury* 26 July 1986, p.5, Hallegraeff & Sumner 1986).

The importance of this dinoflagellate bloom in 1986 to the viability of the D'Entrecasteaux Channel scallop fishery cannot be overstated. The major question facing scallop managers at this stage is, will these events prove to be an isolated incident or can these blooms be expected each year? It should be remembered that prior to a 1985–86 CSIRO plankton survey of Tasmanian waters (which included D'Entrecasteaux Channel), no work had been published on Channel phytoplankton. It is thus possible that *Gymnodinium catenatum* has been present each year with little apparent health risk. The answer to this question will not be known until a number of seasons have been monitored.

Changes in Species Abundance

A third biological consideration is that there have been a number of changes in the relative abundance of scallop species taken in the D'Entrecasteaux Channel. In the 1920's and in the period 1940–70 commercial scallops formed the bulk of the catch, but in the 1930's and since 1982 doughboy scallops have been more abundant.

The causes of the changes in species abundance are not known, but as far as the Channel is concerned, management policy needs to encompass all three species of scallop present, and research on scallop re-seeding should be expanded

to include the doughboy scallop, particularly if it is found that there has been some environmental change in the Channel which favours this species.

Pollution

Fourthly, pollution by human waste such as sewage, insecticide sprays and industrial pollution have been suggested as causes of the declining scallop populations in the Derwent River and D'Entrecasteaux Channel (*The Mercury* 8 July 1910, p.6, 13 June 1969, p.8, Harrison 1975). Scallop sensitivity to pollution is great and is demonstrated by the fact the U.S.A. Environmental Protection Agency now uses scallops as indicators of changing environmental conditions, such as eutrophication and siltation (Robert 1978). With only a few exceptions (e.g. Newell 1969) there is a lack of data on pollution levels in the Channel. However, it seems reasonable that the increasing urbanisation of the Channel environment might lead to increasing pollution levels, with consequent adverse affects on scallop stocks.

Administrative Problems

Over-exploitation

Excessive fishing effort is one of the major problems facing managers of the Channel scallop fishery. When a common resource is utilised there is a tendency for it to be depleted, as each individual exploiting it perceives profits and increases capital investment to maximise his/her share of the resource.

Because the Channel scallop fishery was open to all who wished to fish for scallops, there was a tendency to over-use it while profits could be perceived. This over-use has been exacerbated by the escalation of fishing effort by amateur fishermen.

The major problem arising from over-use of the resource is the effect on the spawning stock level. There is evidence to suggest that scallop stocks in the Channel fluctuate independently of the parental spawning stocks (SFABT Subcommittee 1964, Olsen 1955) but that there may exist a critical population level below which recovery of a decimated population may not occur (Harrison 1965). Whatever the case may be, it is desirable to know the size of an adult spawning stock that is sufficient to ensure adequate recruitment (McKenzie *et al.* 1978).

Dredging Damage

In D'Entrecasteaux Channel the use of dredges to harvest scallops causes significant damage to the scallops and to the sea bed itself. Damage to the scallops of the Channel by dredging was the major subject of a Tasmanian Senate Select Committee Inquiry in 1960 and 1961. The inquiry did not find conclusive evidence on the damage done by the different types of dredge in use, but it did take heed of fishermen's comments and personal observations of the Committee members and recommended the banning of spiked dredges in the Channel (SCLC 1960, 1961).

Overseas experience has shown that dredging can cause considerable physical damage to benthic fauna (Caddy 1973, Dupouy 1983) while in Port Phillip Bay, Victoria, dredging has been implicated in the increase in levels of heavy metals in the water over scallop beds (Fabris 1981). Disturbance of the bottom by dredging and consequent destruction of the prawn habitat has resulted in all dredges being banned in the Shark Bay fishery in Western Australia (Rogers *et al.* 1983). On the other hand, two studies have revealed that little damage is done by dredging (McShane 1981, Butcher *et al.* 1981). This is surprising, but it should be remembered that destruction of the sea bed is related to the sediment type, for example damage to open sandy sea beds, where species diversity is often low, may be minimal (Butcher *et al.* 1981).

Alternatives to scallop dredges include the Queensland-style beam trawl which has been trialed off Table Cape in northern Tasmania. The results indicated that the beam trawl caught fewer by-products such as sponges, bryozoa etc., more legal-size scallops, fewer undersize scallops, and fewer damaged scallops than the dredge (Wolfe 1986).

Scallop Seasons

Scallop seasons are invoked for three major reasons: to maximise the yield per scallop, to protect scallop stock from excessive fishing effort (Rogers *et al.* 1983), and to protect juvenile scallops.

The imposition of a scallop season has been criticised on the grounds that the seasonal limitation on effort does not effectively restrict fishing pressure (SFABT Subcommittee 1964, Mason 1983). However, in the Channel fishery, where scallop stocks are subjected to large fishing pressure, the length of the scallop season has been

one of the major management considerations for regulating fishing effort.

Aquaculture

Marine species currently being farmed in D'Entrecasteaux Channel include Atlantic salmon (*Salmo salar*), rainbow trout (*Salmo gairdnieri*), oysters (*Crassostrea gigas*), mussels (*Mytilus edulis planulatus*), and commercial scallops (*Pecten fumata*); there are now 26 aquaculture farms throughout the Channel and several more about to begin operations.

Two main problems are posed by aquaculture for fisheries managers, the restriction on traditional anchorages and activities for recreational fishermen, and the potential damage to marine ecosystems by waste food and faecal matter from fish farms.

The majority of objections to the establishment of marine farms in D'Entrecasteaux Channel which have been received by the Department of Sea Fisheries have been on grounds that safe anchorages and prime fishing locations are being taken over (J. Grant, pers. comm.). For example, the recent application for a salmon farm lease near Partridge Island resulted in at least 40 objections on the grounds that the farms would take away a protected anchorage and create a navigation hazard.

The development of Atlantic salmon and sea trout farms may involve a significant increase in the nutrient load for the Channel. In Scotland, where these types of farms have been established for over a decade, significant changes to the marine ecosystem have been recorded in the vicinity of the farms. These have included the sediments beneath the fish farms becoming anoxic, the macrofauna becoming impoverished, and the occurrence of marine organisms characteristic of highly enriched sediments (Gowen *et al.* 1985). While it is too early to predict the likely effects of fish farms on the Channel environment, the results here could be much the same. Therefore the Department of Sea Fisheries plans to monitor these by establishing an environmental monitoring section (M. Hortle, pers. comm.), an essential development if problems encountered in fish farms overseas are to be ameliorated here and existing conflicts between recreational fishermen and marine farm applicants successfully resolved.

THE FUTURE FISHERY: AMATEUR OR PROFESSIONAL?

The importance of amateur fishing to Australians is only now becoming apparent. The first national recreational fishing survey, in 1983–84, found that $2200 million was spent on recreational fishing in Australia in the 1983–84 financial year, making it at least as large as the professional fishery (Anon. 1986c). A 1983 Australian Bureau of Statistics (ABS) survey of non-commercial fishing activities (ABS 1984) showed that 49.9% of households surveyed owned fishing rods and reels, 23 713 boats were owned and used for fishing, and 107 000 Tasmanians who fish each year spend approximately $49 million per annum on recreational fishing. Compared with a total commercial catch for 1983–84 of $38 million (Schaap 1986) this shows the importance of amateur fishing to the Tasmanian economy. Scalloping in D'Entrecasteaux Channel has become an important amateur activity for many Tasmanian residents, and according to the president of the TASFA (D. Paton) it probably now rates as the biggest single recreational sea fishery in the country (Anon. 1983a). The major attractions of the Channel for amateur fishermen are that it is within easy reach of Hobart and is a relatively sheltered and safe waterway for small boat usage. While some take scallops for economic reasons, most fish for enjoyment and relaxation. This presents a number of difficulties for scallop managers, who must widen their aims to take account of social objectives such as quality of experience and non-consumptive activities such as underwater photography.

The channel is currently suffering from excessive fishing effort, and its declaration as an amateur-only fishery would be one way to decrease fishing pressure. Although the ratio of amateur to professional boats from the Channel is 7:1, the permissible catch ratio is 1:15 (in 1985): the professional fisherman can take 15 times as many scallops as his amateur counterpart, the professional component thus exerting twice the fishing pressure of the amateur component.

There are, however, arguments for the continuation of the fishery in its existing amateur/professional mode. Firstly, if the scallop stocks are capable of withstanding fishing pressure from both groups, it is difficult to rationalise an amateur-only status for the fishery. This approach is taken in Victoria by the Commercial Fisheries Branch of the Department of Agriculture and Rural Affairs: their

philosophy and policies of management require that the resource should be managed as harmoniously as possible where the resource can support both fisheries (Winstanley 1985). Secondly, the Channel fishery is an important winter living for some professional fishermen, providing a viable alternative to crayfishing for a short while. There are many professional boats with a long historical association with the Channel fishery, and scallop managers throughout the world have shown a tendency to regard historical associations as grounds for a right of access to the resource (e.g. Sturgess et *al.* 1982, Anon. 1985b). These historical association rights, while not enshrined in legal respectability, would make it politically difficult to introduce an amateur-only fishery.

The establishment of a professional-only scallop fishery in the Channel is difficult to justify. Firstly, the Channel stocks are in a depleted state, and many professional fishermen would find it non-viable to fish here. Secondly, the mobilisation of recreational fishermen into a coherent unit via the TASFA would militate against any moves to establish such a professional-only fishery Finally, from the viewpoint of society in general, the benefits of allowing numerous Tasmanian residents access to a safe and sheltered waterway far outweigh the benefits of allowing a select few to extract a living from a depleted fishery.

DISCUSSION AND CONCLUDING REMARKS

The historical catch data (fig. 2) and the recent decline in catch per unit effort (table 1) indicate that the D'Entrecasteaux Channel scallop stocks have been overfished and are in a depleted state. The specific reasons for the depletion of scallop stocks in the Channel are not proven, but the use of the "Sputnik" dredge, the disguised fall in catch per unit effort, increasing pollution levels, and the extra-long scallop seasons of 1964, 1967, 1968 and 1969 could all be included. Whatever the reasons may be, it is imperative that existing stocks be carefully nurtured and enhanced.

Overall Management

The primary management aim should be to ensure the long-term viability of scallop stocks in the Channel in sufficient numbers to support at least an amateur fishery. It is suggested that the D'Entrecasteaux Channel scallop fishery should be amateur-only while scallop stocks are low, the optimum sustainable yield being equated with the yield that guarantees amateur fishermen at least a short season, while protecting the scallop stocks. If stocks increase, a small-scale professional fishery could be allowed, and the small-boat owner who has a history of fishing in the Channel, who cannot safely fish elsewhere, and who relies on the Channel fishery for an important part of his livelihood should be given first option of fishing. If a professional fishery proved viable, a landings tax on scallops should be considered to assist in meeting management costs. Such a tax could be seen as reflecting the costs of the fishermen's actions to Tasmanian society in general.

Any proposed management plan will fail unless it is clearly understood and supported by fishery participants (at present there is reasonable harmony between the amateur and professional fishing components of the fishery and the Department of Sea Fisheries, indicating support for existing management practices). In particular, the close liaison between the Department of Sea Fisheries and the TASFA should be maintained, the participation of the TASFA in the management process should be enhanced by wider publication of the reasons behind management decisions, and the results of the pre-season survey should be widely communicated.

Regulations

The regulations concerning hours of fishing, scallop-size limits and the control of on-board shucking should remain. The present bag limits, which have provided scallop managers with a mechanism for maintaining close control over fishing effort, should also be maintained, and if fishing pressure is deemed excessive they should be tightened. The present ban on the taking of commercial scallops is sensible: it too should be maintained and could be extended to include doughboy scallops if they become scarce.

The licence fee, which needs to be commensurate with management costs (such as those for pre-season surveys, enforcement and research), could be increased. The present bag limit of 400 scallops per day results in approximately 6 kg of scallop meat (D. Fehre, pers. comm.), and at a conservative price of $8 per kg this represents considerable reward to amateur fishermen (assuming they are taking the bag limit each day). An increase in licence fees could contribute towards the administration and enforcement costs of the fishery, and possibly towards the cost of re-seeding depleted areas of the Channel. If licence

fees are increased, the reasons for this should be clearly communicated to participants.

If the Channel fishery should become an amateur-only fishery, the length of the season should be increased to avoid the congestion which accompanies the present short season. If the fishery remains an amateur/professional fishery then divers-only areas should be designated for the protection of the divers. The current system of opening and closing fishing areas seems reasonable, and provides a degree of protection to over-exploited and juvenile stocks. Consideration should be given to the permanent closure of one area, so that the effects of fishing on adjacent areas could be more easily assessed.

The lip dredge is conditionally recommended for continued use in the Channel fishery, pending further research on the damage done by the different types of scallop dredges.

The annual, pre-season survey should continue and be enhanced by diving surveys and, possibly, occasional underwater television monitoring of the scallop stocks; permanently closed areas should also be monitored for signs of alteration in the relative abundances of doughboy, commercial or queen scallops. The results of these surveys should be published and distributed as widely as practicable prior to the opening of the season, possibly in conjunction with the sale of a licence.

Enforcement and Fines

It seems likely that enforcement levels in the Channel could not be increased greatly owing to the shortages of resources but some reassessment of enforcement activities is required. In particular, an increase in surveillance levels by the Marine Board Inspectors should be considered.

Penalties for transgressions need to be increased so that poachers and cheats will be dissuaded from further breaching the law. Consideration should be given to having a Department of Sea Fisheries barrister present cases in court to bring about a greater realisation of the importance of protecting the fishery.

Research

Overall, research on scallops in the Channel should be upgraded. A spatfall monitoring programme implemented at selected sites would lead to a better understanding of the biology of the Channel scallops and the factors which influence spatfall, and might provide early estimates of recruitment, as well as of scallops for re-seeding purposes.

Re-seeding research should be increased, and the possibilities of generating income by the sale of rights to fish a re-seeded area should be examined. In Golden Bay the New Zealand Government, in conjunction with Japanese consultants, re-sowed an area of depleted scallop beds in 1984; harvesting of the area was expected to commence in November 1986 (Anon. 1986b). The establishment and harvesting of re-seeded areas thus seems possible, and may be appropriate for the D'Entrecasteaux Channel. Income for the scheme could be generated from the sale of rights to fish the re-seeded area.

Aquaculture of scallops in the Channel should be encouraged. There is already an experimental farm at Tinderbox (G. Squires, pers. comm.); such farms should be assisted, as they would contribute directly to the strength of the annual scallop recruitment and thereby enhance the Channel scallop stocks.

A full assessment is needed of the damage done by different scallop dredges, and the development of new fishing techniques should be encouraged. This encouragement could take the form of special permits to trial dredges in the Channel, or help for applicants in obtaining research and development grants from sources such as the Fishing Industry Research Committee. There is also a need for instruction for fishermen, showing the correct method of towing dredges, to offset the damage done by towing full or incorrectly set dredges. This also could be achieved by distributing a leaflet with the scallop licence.

Conclusion

The D'Entrecasteaux Channel scallop fishery is of great historical and social importance, and its present depleted state is deplorable. The survey report of 1985 contains three lines of management aims and objectives (Zacharin 1985) which are totally inadequate to prevent *ad hoc* decisions on fishing regulations, amateur/professional participation in the fishery, or research aims and objectives. If the scallops in the Channel are to provide food, recreation and possibly economic returns in the long term, a comprehensive management plan with clear goals and objectives is required.

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REFERENCES

ANON., 1947: History of the Tasmanian Scallop Fishery (compiled by research officers of the Fisheries Division, Council for Scientific and Industrial Research and made available by courtesy of the CSIRO Tasmania Division), copy from State library, Hobart.

ANON., 1962: The scallop fishery of Tasmania. *Service* 26(5): 112–117.

ANON., 1967: Tasmanian fisheries research report. *Aust. Fish. Newsl.* 26(8): 23.

ANON., 1974: Situation Report Tasmania. Unpubl. rep. of the Sea Fisheries Division, Department of Agriculture.

ANON., 1980: Fishing port of Kettering. *FINTAS* 2(5): 2–7.

ANON., 1983: July doughboy season. *FINTAS* 6(2): 4.

ANON., 1984: Channel season an amateur picnic. *FINTAS* 7(3): 14–16.

ANON., 1985a: Tough channel scallop season last July was a shock to many. *FINTAS* 8(3): 23.

ANON., 1985b: Status and management of the Nelson/Marlborough scallop fishery, 1985. Unpubl. rep., Ministry of Agriculture and Fisheries, Wellington: 1–14.

ANON., 1986a: Scallop success opens new doors for Tasmanian aquaculture. *FINTAS* 9(2): 3–7.

ANON., 1986b: Status and management of the Nelson/Marlborough scallop fishery, 1986. Unpubl. rep., Ministry of Agriculture and Fisheries, Fisheries Management Division Rep. No.12, Wellington: 1–14.

ANON., 1986c: Recreational fishing in Australia. *Mar. Stud.* 27: 13–16.

AUSTRALIAN BUREAU OF STATISTICS, 1984: Household fish consumption and non-commercial fishing activities, Tasmania, October 1982. *ABS Cat.* no.7601.6. Australian Bureau of Statistics, Hobart: 1–10.

BUTCHER, T., MATTHEWS, J., GLAISTER, J & HAMER, G., 1981: Study suggests scallop dredges causing few problems in Jervis Bay. *Aust. Fish.* 40(9): 9–13.

CADDY, J.F., 1973: Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. *J. Fish. Res. Board Can.* 30(2): 173–180.

CAMPBELL, G.R., 1984: A final report to the Fishing Industry Research Committee on the recruitment into commercial stocks of the saucer scallop *Amusium japonicum balloti*. Unpubl. rep. to the Fishing Industry Research Committee.

COMMISIONERS OF FISHERIES, 1923: Commissioners of Fisheries report for the year 1921–22. *Tas. J. Print. Pap. Parl.* LXXXVII (51): 1–9.

DEPARTMENT OF AGRICULTURE, 1949: Annual report for 1947–48. *Tas. J. Print. Pap. Parl.* CXXIX (18): 1–36.

DEPARTMENT OF AGRICULTURE, 1953: Annual report for 1952–53. *Tas. J. Print. Pap. Parl.* CXLIX (24): 1–36.

DEPARTMENT OF AGRICULTURE, 1965: Annual report for 1964–65. *Tas. J. Print. Pap. Parl.* 173 (2), 64: 1–96.

DEPARTMENT OF AGRICULTURE, 1970: Annual report for 1969–70. *Tas. J. Print. Pap. Parl.* 183(2), 70: 1–93.

DEPARTMENT OF AGRICULTURE, 1971: Sea Fisheries Division report by the Director of Agriculture for 1970–71. *Tas. J. Print. Pap. Parl.* 185(2), 52: 1–16.

DEPARTMENT OF SEA FISHERIES, 1986: Unpubl. correspondence of the Department of Sea Fisheries, 18 June 1986.

DUPOUY, H., 1983: Comparative study of scallop drags used in France. *Can. Trans. Fish. Aquat. Sc.* 4901: 1–11.

FABRIS, G.J., 1981: Effect of scallop dredging on mobilisation of heavy metals in Port Phillip Bay. A perspective. *Mar. Sci. Lab. Queenscliff Tech. Rep.* 3: 1–4.

FAIRBRIDGE, W.S., 1953: A population study of the 'commercial' scallop, *Notovola meridionalis* (Tate) (Lambellibranchiata, Pectinidae). *Aust. J. Mar. Freshw. Res.* 4(1): 1–40.

FRANKLIN, A., PICKETT, G.D. & CONNOR, P.M., 1980: The scallop and its fishery in England and Wales, Ministry of Agriculture, Fisheries and Food. *Dir. Fish. Res., Lab. Leafl.* 51: 1–19.

GOWEN, R.J., BRADBURY, N.B. & BROWN, J.R., 1985: A summary report on the preliminary study of the ecological impact of salmon farming in Scottish coastal waters. Unpubl. rep. Dep. Biol. Sci., The University, Stirling, Scotland.

GWYTHER, D. & SAUSE, B., 1985: Towards a longer term strategy for Port Phillip scallop fishery management. *Aust. Fish.* 44(8): 4–8.

HALLEGRAEFF, G. & SUMNER, C., 1986: Toxic plankton blooms affect shellfish farms. *Aust. Fish. Reprint* 158: 4 pp.

HARRIS, J.G.K., 1981: 1981 D'Entrecasteaux Channel scallop survey. Unpubl. rep. of the TFDA Research Laboratory: 5 pp.

HARRIS, J.G.K., 1982: 1982 scallop survey — D'Entrecasteaux Channel and Great Oyster Bay. Unpubl. rep. of the TFDA Research Laboratory: 2 pp.

HARRIS, J.G.K.,1983: Scallop survey — preliminary report. Unpubl. rep. of the TFDA Research Laboratory: 4 pp.

HARRISON, A.J., 1965: Tasmanian scallop fishery and its future. *Aust. Fish. Newsl.* 24(5): 9–13.

HARRISON, A.J., 1966: Tasmanian scallop research, Southern Pelagic Project Committee technical session. CSIRO Situation Report, Cronulla, New South Wales.

HARRISON, A.J., 1975: Fisheries management with particular reference to commercially exploited fish stocks around Tasmania. *In* Banks, M.R. & Dix, T.G. (Eds): *RESOURCES OF THE SEA.* Royal Society of Tasmania, Hobart: 81–92.

LANGFORD, R., 1959: Scallop dredging position. Unpubl. correspondence of the Sea Fisheries Advisory Board 1953–59. Tasmanian Archives, Hobart, CB.32.

LANGLOIS, D.R. & COOPER, R.J., 1978: Hydrology of the Derwent Estuary and surrounding coastal waters. *Mar. Invest. Section Prog. Rep.* 2. Electrolytic Zinc Co. of Australasia Ltd, Environmental Services Division: 28 pp.

McKENZIE, C.L., MERRILL, A.S. & SERCHUK, F.M., 1978: Sea scallop resources off the north eastern US coast. *Mar. Fish. Rev.* 40(2): 19–23.

McSHANE, P.E., 1981: The effect of scallop dredging on the macrobenthos of a muddy environment in Port Phillip Bay. *Mar. Sci. Lab., Queenscliff, Tech. Rep.* 4: 1–16.

MASON, J., 1983: *SCALLOP AND QUEEN FISHERIES IN THE BRITISH ISLES.* Fishing News Books Ltd, Farnham: 141 pp.

NEWELL, B.S., 1969: Dispersal of pulp mill effluent in Hospital Bay, Tasmania. CSIRO, Australia. *Div. Fish. Oceanogr. Rep.* 44. : 1–28.

OLSEN, A.M., 1955: Underwater studies of the Tasmanian commercial scallop, *Notovola meridionalis* (Tate) (Lamellibranchiata: Pectinidae). *Aust. J. Mar. Freshw. Res.* 6: 392–409.

OSHIMA, Y., HASEGAWA, K., YASUMOTO, P., HALLEGRAEFF, G. & BLACKBURN, S., 1987: Dinoflagellate *Gymnodinium catenatum* as the source of PSP toxins in Tasmanian shellfish. *Toxicon* (in press).

PERRIN, R.A. & HAY, P., 1987: A history of the Tasmanian scallop industry: Diagnosing problems of management. *Pap. Proc. R. Soc. Tasm.* 121: 1–14.

ROBERT, G., 1978: Biological assessment of the Bay scallop (*Argopecten irradians*) for maritime waters. *Tech. Rep. Fish. Mar. Serv. (Can.)* 778: 1–13.

ROGERS, P., HANCOCK, D. & STEWART, G., 1983: Report of the scallop fishery management group, March 1983. *Fish. Management Pap.* Fisheries Department, Western Australia.

SCHAAP, A., 1986: Tasmanian recreational sea fishing. Paper given at the Recreational Fishing Confederation Conference in Canberra, September 1986.

SEA FISHERIES ADVISORY BOARD OF TASMANIA, 1959: Unpubl. correspondence of the Sea Fisheries Advisory Board. Tasmanian Archives, Hobart, CB.32.

SEA FISHERIES ADVISORY BOARD OF TASMANIA SUB-COMMITTEE ON THE SCALLOP FISHERY, 1964: Interim report. Unpubl. rep., CSIRO Division of Fisheries and Oceanography, Cronulla: 1–16.

SEA FISHERIES BOARD OF TASMANIA, 1930: *Report of the Board for the years 1926–29, Tasmania.* Government Printer, Tasmania.

SEA FISHERIES BOARD OF TASMANIA, 1933: *Report of the Board for the years 1930–32, Tasmania.* Government Printer, Tasmania.

SEA FISHERIES BOARD OF TASMANIA, 1938: Unpublished Sea Fisheries Board correspondence. Tasmanian Archives, Hobart, ADG 1/165(7) file 113/38.

SEA FISHERIES DIVISION, 1974: D'Entrecasteaux Channel survey. Unpubl. rep. of the Sea Fisheries Division, Cruise Report CR 354/355/74.

SEA FISHERIES DIVISION, 1976: D'Entrecasteaux Channel survey. Unpubl. rep. of the Sea Fisheries Division.

SEAL, M., ALLPORT, C., JOHNSTON, R.M., RIDDOCH, A., SWAN, J., WEBSTER, A.G., BELSTEAD, C.T. & SWAN, E.D., 1883: Royal Commission on the Fisheries of Tasmania, Report of the Commissioner. *Tasm. House Assem. J.* XLIII 132: I–LXVI, 1–86.

SELECT COMMITTEE OF THE LEGISLATIVE COUNCIL, 1960: Scallop fishery of Tasmania. Interim report of Select Committee of the Legislative Council, with Minutes of Proceedings. *Tasm. J. Print. Pap. Parl.* 163(74): 6.

SELECT COMMITTEE OF THE LEGISLATIVE COUNCIL, 1961: Scallop fishery of Tasmania. Final report of Select Committee of the Legislative Council, with Minutes of Proceedings. *Tasm. J. Print. Pap. Parl.* 165(49): 1–8.

SERCHUK, F.M., WOOD, P.W., POSGAY, J.A. & BROWN, B.E., 1979: Assessment and status of sea scallop (*Placopecten magellanicus*) populations off the northeast coast of the United States. *Proc. Nat. Shellfish. Assoc.* 69: 161–191.

SERCHUK, F.M. & RAK, R.S., 1983: Biological characteristics of offshore Gulf of Maine sea scallop populations: size distributions, shell height-meat weight relationships and relative

fecundity patterns. *Nat. Mar. Fish. Service, Northeast Fish. Center, Woods Hole Lab., Ref. Document* 83-07: 42 pp.

SMITH, C., 1984: D'Entrecasteaux Channel 1984 scallop survey — report. Unpubl. rep. of the TFDA Research Laboratory: 3 pp.

STURGESS, N.H., DOW, N. & BELIN, P., 1982: Management of the Victorian scallop fisheries: retrospect and prospect. *In* Sturgess, N.H. & Meany, T.F. (Eds): *POLICY AND PRACTICE IN FISHERIES MANAGEMENT.* Australian Government Publishing Service, Canberra: 277–315.

TASMANIAN FISHERIES DEVELOPMENT AUTHORITY, 1982a: Review of Tasmanian fisheries and the operation of the Fisheries Development Authority 1977–81. *Tasm. J. Print. Pap. Parl.* 207(2), 35: 21.

TASMANIAN FISHERIES DEVELOPMENT AUTHORITY, 1982b: Unpublished correspondence of the Tasmanian Fisheries Development Authority, letter from the Tasmanian Sub Aqua Club, 16 August 1982.

TASMANIAN FISHERIES DEVELOPMENT AUTHORITY, 1983: Sixth annual report for the year ended 30 June 1983. *Tasm. J. Print. Pap. Parl.* 209(2), 63: 1–17.

TASMANIAN FISHERIES DEVELOPMENT AUTHORITY, 1984: Seventh annual report for the year ended 30 June 1984. *Tasm. J. Print. Pap. Parl.* 211(57): 11.

TUBB, J.A., 1946: The Tasmanian scallop (*Pecten medius* Lamarck). First report on tagging experiments. *Aust. Counc. Sci. Ind. Res. J.* 19: 202–211.

WINSTANLEY, R.H., 1985: Marine fisheries management in Victoria — balancing commercial and amateur fishing interests and community expectations against limited resources. *Fish. Wildl. Serv. Vic., Mar. Fish. Rep.* 4: 14 pp.

WOLFE, D., 1986: Scallop trawl shows its potential. *FINTAS* 9(2): 15–17.

YENTSCH, C.M., 1984: Paralytic shellfish poisoning. An emerging perspective. *In* Ragelis, E.P. (Ed.): *SEAFOOD TOXINS.* American Chemical Society Symposium Series 262. Washington D.C.: 9–23.

ZACHARIN, W., 1985: D'Entrecasteaux Channel scallop survey, 1985. Unpubl. rep. of the Department of Sea Fisheries Research Laboratory: 4 pp.

ZACHARIN, W., 1986: D'Entrecasteaux Channel scallop survey, 1986. Unpubl. rep. of the Department of Sea Fisheries Research laboratory: 7 pp.

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ROYAL SOCIETY OF TASMANIA
ANNUAL REPORT FOR THE YEAR 1988

The Council has the honour to present to members the following report on the activities of the Society during the year.

COUNCIL AND OFFICE BEARERS

Patron
Her Majesty the Queen

President
His Excellency the Governor of Tasmania
Sir Phillip Bennett AC, KBE, DSO

Vice Presidents

Mr C.A.H. Payne
Prof. O.M. Roe

Council

Mr P.M. Bennison
Mr G. Davis
Dr P.G. Quilty
Dr J.S. Rogers
Mr R.R. Shepherd
Prof. D.M. Stoddart
Mr C.B. Tassell
Mr M.J. Walsh
Mr P.G. Webb

Honorary Secretary
Mr D.R. Gregg

Honorary Treasurer
Mr T.A.H. Knight

Honorary Auditor
Mr R.J. Dwyer

Honorary Editor
Dr M.R. Banks AM

Assistant Honorary Editor
Dr S.J. Smith

President

H. E. General Sir Phillip Bennett took the chair as President of the Society, at the Annual General Meeting and at the Annual General Meeting of the Northern Branch. He also took the chair at the initial Sir Joseph Banks Memorial Lecture at Hobart on 25 August. Sir Phillip opened the Hyperbaric and Diving Medicine Meeting on 4 November and attended the initial lecture by Dr Janet Vial which was delivered to the November General Meeting of the Society.

Keith Edward James Robinson 1912–88

Keith Robinson died in Launceston on 16 March 1988. He joined the Society in 1964. He served on the Council of Northern Branch almost continuously from 1967 and was most recently Honorary Treasurer. He was Vice-President of the Society in 1976–77 being the only Vice-President, ever, resident outside southern Tasmania, and was a member of the Council from 1971 to 1980. He was elected an Honorary Life Member of the Society in 1981.

Mr Robinson made major contributions towards the development of museums and art galleries in Tasmania as Chairman of the Government's Museums and Art Galleries Advisory Committee in 1977–80. He was a Trustee of the Tasmanian Museum and Art Gallery from 1983 to 1987.

Deaths of Members

The deaths of the following members are also recorded with regret:

Dr R.J. Ford
Mr W.R. Robertson
Mrs M.J. Salmon

Annual Meeting

At the Annual Meeting on 1 March, Dr P.G. Quilty retired as Vice-President and Mr P.M. Bennison and Professor O.M. Roe as Members of the Council. The following were elected:

Vice-President	Prof. O.M. Roe
Members of Council	Mr P.M. Bennison
	Prof. D.M. Stoddart
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Increase in Subscriptions

At the October General Meeting it was resolved, on the recommendation of Council, that from the beginning of 1989, subscription be as follows:

Members receiving the *Papers and Proceedings*	$20.00
Members not receiving the *Papers and Proceedings*	$12.00
Associate members	$8.00
Life members	$300.00

Subscriptions had not been increased since the beginning of 1978. Since then they had been $12 (with *Papers and Proceedings*), $8 (without *Papers and Proceedings*), $5 (associate) and $200 (life membership).

Membership

The membership is 449, a decrease of 16, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	2	7
Life Members	12	35
Ordinary Members receiving *Papers and Proceedings*	62	288
Ordinary Members not receiving *Papers and Proceedings*	51	100
Associate Members	13	19
	140	449

Council Meetings

The Council met four times during the year.

Sir Joseph Banks Memorial Lectures

The Sir Joseph Banks Memorial Lectures were launched splendidly at the Hobart Town Hall on the evening of Thursday, 25 August 1988, under the chairmanship of the President of the Society, His Excellency General Sir Phillip Bennett. Some 300 members and others attended the lecture in Hobart. Sir David Smith FRS, the Sir Joseph Banks Memorial Lecturer and Principal and Vice-Chancellor of Edinburgh University, spoke on *Commemorating Sir Joseph Banks — Symbiosis and the Concept of Mutual Benefit*. He had been nominated by the President of the Royal Society of London, and was accompanied by his wife during the first part of the tour.

Sir David repeated his lecture as follows:

Friday 26 August Launceston, Northern Branch, Royal Society of Tasmania
Monday 29 August — Canberra, Australian Academy of Science
Tuesday 6 September — Sydney, Royal Society of New South Wales
Tuesday 13 September — Brisbane, Royal Society of Queensland
Tuesday 20 September — Melbourne, Royal Society of Victoria
Thursday 22 September — Adelaide, Royal Society of South Australia
Wednesday 28 September — Perth, Royal Society of Western Australia
Monday 7 November — London, Royal Society

The lecture was heard by a total of some 1100 people and is to be published in Volume 123 of the *Papers and Proceedings*.

A booklet, funded by The Australian Bicentennial Authority, was published for the lectures and was distributed to those attending. The Council is grateful for the work done by Mr Donald Hughes in compiling and arranging the publication of the booklet.

A commemorative medal was issued to mark the occasion. The medal, designed and modelled by Stephen Walker of Campania, was cast in an edition of 150 in bronze and offered for sale at $80 each. A single silver medal was cast and this was presented to Sir David Smith. The obverse shows a portrait of Sir Joseph Banks. The reverse shows H.M. Bark *Endeavour* with *Banksia serrata* and a lizard chosen by Banks for his personal armorial bearings.

Many people were involved in the project. The Council would, in particular, like to record its appreciation of the contribution made by Mr P.G. Webb, Honorary Life Member, who in 1978 proposed that the lectures be held.

The project could not have proceeded without the sponsorship of travel generously provided by Qantas and Ansett. The Australian Bicentennial Authority endorsed the lecture series in 1986 and provided a grant for the publication of a booklet.

Other assistance for the lectures in Tasmania and for the visit of Sir David and Lady Smith came from His Excellency General Sir Phillip Bennett and Lady Bennett, the University of Tasmania, Tasmanian State Institute of Technology, Hobart City Council, Tasmanian Museum and Art Gallery, Queen Victoria Museum and Art Gallery, Society for Growing Australian Plants (Tasmanian Region), Hydro-Electric Commission, Department of Agriculture, Tasmanian Arboretum (Eugenana), Safcol (Tas.) Pty Ltd, Port Arthur Historic Site Management Authority, Mr Jon Grey, Professor W.D. Jackson, and Dr Anne Louise Ponsonby.

Library

The library has continued to function smoothly during the year. Dr Stefan Petrow was responsible for the library for the first half of the year, and since his temporary transfer to another position within the University Library, Mrs Mary Anne Secker has been acting librarian.

During the year 443 visitors to the library signed the register, 234 journals were recorded as being consulted in the library, and there were 138 loans from the serials section. The library supplied 110 photocopied items in response to interlibrary loan requests. The decrease in interlibrary loans over the past three years is likely to be a result of the increase in interlibrary loan charges throughout Australia. Binding of Royal Society serials amounted to 213 volumes in 1988.

As usual the index for the 1987 volume of the *Papers and Proceedings* was prepared. In December, the two issues of the 1988 volume were distributed to 293 exchange partners. An exchange agreement was commenced with the Matra Museum, Hungary, from whom we have received a back-set of *Folia Historico-Naturalia Musei Matraensis*. This exchange was initiated by Council member Dr J.S. Rogers during a visit to Hungary.

Two special projects were completed during the year. Dr Petrow produced a useful list of serials currently received by the library. This is available from the library on request. Mrs Secker completed an assessment of the estimated growth of the collection for the next five years, with recommendations for an increase in shelving to accommodate the collection.

Publications

A subsidy from the Antarctic Division, Commonwealth Department of Science, and the Tasmanian Department of Lands, Parks and Wildlife enabled publication by the Society of the Proceedings of a Symposium on Macquarie Island held in Hobart in May 1987. The Proceedings were published in August as Volume 122, Part 1, of the *Papers and Proceedings*, and comprised 33 papers involving 44 authors and totalling 318 pages. Part 2, comprising 20 papers involving 20 authors and totalling 197 pages, was published in mid-November. Both parts contained papers on a wide range of topics from the physical and natural sciences, history and political science.

A publication arising from the symposium on the Tasman Peninsula held by the Society in November 1986 was approaching completion at the end of 1988. At that time two papers had been accepted for publication in Volume 123 and a further 11 papers had been received and were being processed.

The Honorary Editor and Honorary Assistant Editor acknowledge with thanks the help of Mrs Alison Jones as sub-editor and Mrs June Pongratz as typist and formatter. Staff of the Government Printer's Office were courteously helpful.

The Society is once more indebted to Dr Banks and Dr Smith for their dedicated editorial work.

Lectures

The following interesting and varied lectures were given at General Meetings during the year:

March — "The Noselessness of Man" Prof. D.M. Stoddard, Dept of Zoology, University of Tasmania

April (held on 29 March) — "Pain" Dr George Merridew, Launceston General Hospital

May — "The Tasmanian Herbarium" (held at University of Tasmania) Dr A.E. Orchard, Tasmanian Herbarium, Tasmanian Museum and Art Gallery

June — "Radio Astronomy in Tasmania" Dr P.A. Hamilton, Dept of Physics, University of Tasmania

July — "Maritime Education and Training" Captain Peter McGovern, Australian Maritime College

August — "Jave la Grande: The Enigma of the Dieppe Maps" (joint meeting with the Tasmanian Historical Research Association and the Tasmanian Branch of the Library Association of Australia, held at CSIRO Laboratories) Dr Helen Wallis, former Map Librarian of the British Library

September — "Antarctic Ice: A Record of Global Environmental and Climatic Change" Dr Claude Lorius, President, Scientific Committee on Antarctic Research

October — "Minerals and Rocks in Electron Microscopy" Prof. A.C. McLaren, Research School of Earth Sciences, Australian National University

November — "Free Radicals in Health and Disease" (held at Royal Hobart Hospital) Dr Janet Vial, Dept of Medicine, University of Tasmania.

Members visited the new building of the Tasmanian Herbarium following the May General Meeting.

A visit to the University of Tasmania radio telescope at Mt Pleasant, Cambridge, under the guidance of Dr P.A. Hamilton, was made on Saturday morning, 11 June.

Hyperbaric and Diving Medicine Meeting

A meeting on *Hyperbaric and Diving Medicine* was held, in association with the Society, in Hobart, 4–6 November. The meeting which was organised by Dr P.W. McCartney, was opened by the President of the Society, H.E. General Sir Phillip Bennett, at the Royal Hobart Hospital. The initial lecture, by Dr Janet Vial, was delivered to the November General Meeting of the Society.

Northern Branch

Chairman	Mr P.G. Webb
Vice-Chairman	Dr D. Churton
Honorary Secretary	Mr C.B. Tassell
Honorary Treasurer	Mr B. Pike
Council Members	Mr A.T. Orr
	Mr E.H. Fist
	Mrs M. Cameron
Branch Representatives on Council of Society	Mr P.G. Webb
	Mr C.B. Tassell

The Branch Council met three times during the year.

The following lectures were given at General Meetings:

March — "French Exploration in the Pacific" Mr N.J.B. Plomley, Hon. Research Associate, Queen Victoria Museum
April — "Dinosaurs" Mr C.B. Tassell
May — "Conservation Architecture and the Church of Apostles" Mr P. Staughton
June — "An Introduction to John Bowen and the Risdon Settlement" Rev. Canon R.D. Tyson
July — "From the Beginning, A History of the Launceston Technical College 1895–1988" Mr Bruce Proverbs
August — "The History of the Cradle Mountain–Lake St Clair National Park" Mr Tim Jetson
September — "Mars the Red Planet" Mr M.R. George, Curator of Physical Science, Queen Victoria Museum
October — "The Greenhouse Effect" Dr P.G. Quilty, Antarctic Division
November — The Eldershaw Lecture 1988 Mr N.J.B. Plomley
December — Member's Night
"Boomerang" Mr J.F. Kolkert
"Station Life in the Outback" Mrs M.P. Little
"Launceston 100 Years Ago" Mr H. Stancombe.

Excursions and special events:

26 August — Sir Joseph Banks Memorial Lecture by Sir David Smith
27 August — Visit to Tasmanian Arboretum at Eugenana with Sir David and Lady Smith.

Nominees to Other Bodies

The Council re-elected Mr A.R. Neilson and Dr P.G. Quilty to serve a further term on the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The 1988 State Budget provided a grant of $1 384 000 to the Tasmanian Museum and Art Gallery, an increase of 9.6% over the allocation in the 1987 Budget. Of this, 81% will be spent on salaries and related costs, a slight decrease from the 83% of recent previous years.

The new building for the Tasmanian Herbarium on the University of Tasmania Sandy Bay Campus, occupied in November 1987, was opened by the Hon. Peter Rae, Minister for Education and the Arts, on 17 February 1988.

The restoration of the exterior and of the ground floor of the 1824 Commissariat Bond Store has been completed, with the assistance of grants from the National Estate Programme of the Australian Heritage Commission, the Australian Bicentennial Authority, Laver Pty Ltd, and the National Trust Preservation Fund (Hobart). Assistance for the project was provided by the Lift Manufacturers Association of Australia Ltd, which restored the 1900 hydraulic lift, and Philp Lighton Floyd Beattie. This first stage of the restoration of the Bond Store was declared completed by H.E. General Sir Phillip Bennett, Governor of Tasmania, at the Bond Store Ball and Supper held on 18 June 1988.

The Private Secretary's Cottage, dating back probably to 1813, in the Museum complex is being restored with the assistance of students and staff of the Hobart Technical College to mark its centenary.

During 1988, 134 661 people visited the Museum and Art Gallery, compared with 107 364 in 1987.

A year of Bicentennial exhibitions started on New Year's Day 1988 with the opening to the public of *Tasmanian Vision*, an exhibition of the art of 19th-century Tasmania, sponsored by the SBT Bank and indemnified jointly by the Tasmanian and Australian Governments. The exhibition was seen by 38 000 people in Hobart and 22 000 people in Launceston. It was a resounding popular success and attracted Australia-wide attention. Selections from the exhibition were shown later in the year in Burnie and Devonport.

The Bicentennial year ended with the showing of *The Great Australian Art Exhibition 1788–1988* which opened on 20 December. This exhibition was presented by the Australian Bicentennial Authority and managed by the International Cultural Corporation of Australia.

Another Bicentennial exhibition *Shipwreck! Discoveries from our earliest shipwrecks 1622–1797*, also managed by ICCA, was opened by Her Majesty Queen Beatrix of the Netherlands on 27 October and shown until the end of November.

Other temporary exhibitions shown during the year included: *Captured Images, photographs from the collection* (December 1987–April), *Holzner Paintings* (February–April), *Fred Williams, a retrospective*

(April–May), *The ANZ Bicentennial Art Commissions* (June–July), *George Davis, portraits, people and the figure* (June–August), *Irish Gold and Silver* (July–August), *Antarctic Journey, three artists in Antarctica* (July–August), *Innocent Reading for Origin, photographs and text by Elizabeth Gertsakis* (July), *Selected Art Acquisitions 1984–88* (August–October), *Four Aspects of Contemporary Japanese Ceramics* (September–October) and *The Changing Silhouette, Fashion 1888 to 1988* (October–February 1989).

On 10 July 1988, the remaining Tasmanian Aboriginal bones held under the *Museums (Aboriginal Remains) Act* 1984 were handed over to the Aboriginal Trustees appointed under the Act.

Dr Gintaras Kantvilas took up the new position of Curator of Cryptogamic Botany in September 1988.

Mr Hendrik Kolenberg, Curator of Art since 1980, resigned as from the end of 1988 to take up a new position at the Art Gallery of New South Wales.

The Art Foundation of Tasmania continued to encourage support from the private sector for the Museum and Art Gallery. Funds were provided through the Foundation for the following purchases: *Heard Island icon (Admiralty Hut)* by Jan Senbergs, 1987, acrylic on canvas (with funds provided by the Australian and New Zealand Banking Group Ltd); *Nest of premonitions* by James Gleeson, 1987, oil on canvas (with funds provided in part by the Friends of the Tasmanian Museum and Art Gallery Inc.); *Head of a girl* by Lyndon Dadswell, *c.*1934, bronze; *Designs for interior of Government House, Hobart,* 1856, by unknown artist (John Wiltson), 4 gouache and watercolours; *Forty pages from Antarctica* by Bea Maddock, 1988, 40 etchings on 21 sheets; Two Tasmanian tokens — halfpenny, E.F. Dease, Hobart, muled with H.J. Hall, Christchurch, NZ, and penny, O.H. Hedberg with "Australia" seated pattern on reverse (with funds provided by the Tasmanian Teachers Credit Union Co-operative Society Ltd); *Heard Island Headland* by John Caldwell, 1988, pencil, oil and watercolour; Barnes collection of photographica, some 700 items dating from the birth of photography up to the present. The Foundation also provided funds to assist with the cost of *Tasmanian Vision*.

The Friends of the Tasmanian Museum and Art Gallery Incorporated provided funds towards the purchase of *Nest of premonitions* by James Gleeson.

Dr J.E.S. Townrow was re-elected by the Council to serve a further term on the Board of Trustees of the Royal Tasmanian Botanical Gardens. She reports on the year's activities:

In spite of an unusual number of changes in key staff personnel and a series of continuing frustrations, 1988 has been a year of achievement.

The Superintendent, Mr Tony May, was on Long Service Leave for three months during which his place was ably filled by the Senior Foreman, Mr Jim Cane.

Stage II of the Technical Support Services Centre reconstruction has been completed with extensive demolition of old buildings, updating and rationalisation of electrical, drainage and water supply services, and erection of the new coolhouse adjacent to the new glasshouse, with construction of soil bins and a soil mixer, and a concrete apron for the foreman's office, maintenance workshop, store and poisons store. The latter buildings form part of Stage III due to start in early 1989.

A side-effect of the building operations has been inaccurate logging of visitor numbers with visitors bypassing the automatic counters through the main gates left open to allow access to builders and trade vehicles. A new gate installed at the northern end of the Gardens was also left unmonitored. Even so visitors recorded numbered about 240 000. This compared very favourably with 157 000 recorded ten years ago (1978) and surely reflects the considerable improvements and attractions completed in that time.

These added attractions are due in large measure to the efforts of the Landscape Architect, Dr Joseph Vitesnik, who retired on 31 March. Major projects undertaken during his 19 years of devoted service include the Floral Clock and surrounding display, the rockery approaching the main entrance, the Old Fernery and the New Fernery landscaping, the display and landscaping round the French Memorial Fountain, the development of the Playground Area and associated Gazebo, the installation and surrounds of the Syme Memorial Fountain, the design and construction of the Easy Access Garden, the Herb Garden, the Cactus House, the Fuchsia House and the construction and landscaping of the new Rhododendron and Azalea Section near the AMP Archway. His latest and most outstanding achievement was the planning and construction of the Japanese Garden (1984–86) based on the proposals of the Japanese landscape designers from Hobart's sister city, Yaisu. Dr Vitesnik also planned a reciprocal Australian Garden for Yaisu. The Japanese Garden continues, with the Conservatory, to be the most popular destination with the public. Due to financial stringency the Trustees have regretfully decided that his position must remain vacant for the time being.

The new Education Officer, Mr Andrew Smith, was appointed in August. Formerly Education Officer with the National Parks and Wildlife Service, his very lively talent, enthusiasm and innovative ideas have already had a marked impact on the Museum and on services offered to school children and the public. Christopher Robin, Winnie the Pooh and Owl can be discovered residing along with the bees (and honey) in the ancient oak tree outside the Museum, to the great joy of children of all ages. Inside the Museum the displays of carnivorous plants, aquatic and marine plants complete with native fish, Birds of the Gardens and the see-through beehive are extended with his eye-catching informative models, posters and cartoons. His future plans include training sessions for Friends of the Gardens to enable them, for example, to lead special feature walks in the Gardens. He keenly anticipates a new education centre long desired and worked for by the Trustees.

The new Nursery Foreman, Mr Wayne Cole, and his staff are to be congratulated on having weathered the

considerable frustrations of the past year's staff changes and building reconstruction, playing "musical glasshouses" and contending with extended periods of jackhammering. They and the plants appreciate their greatly improved working and growing conditions as amply demonstrated by the magnificent Spring Conservatory display. Their task has been further aided by the development of a new depot area for storage of compost, soil and gravel, etc., at the northern end of the Gardens. These materials were previously held at the Cornelian Bay Cemetery.

The Trust and the Hobart City Council contributed much effort to increase the Gardens' parking facilities and improve road safety in the vicinity of the Main Gate in a joint project funded by a State Government Minor Works Programme. Stage I was completed in September with the provision of imaginatively conceived angle parking cut into the bank on the west side of the approach road, and modified kerbing and road markings on the east side.

There has been some further construction in the Easy Access Garden, though frustration continues for Mrs Pat Mavromatis, Horticultural Therapist, because of the delay in completion of the Demonstration Garden commenced in 1986. The area for outdoor teaching and raised garden beds has been in use for 12 months.

Horticultural Therapy classes continued on a regular basis throughout the year — the most significant being the commencement of classes from "Special Schools" for children with intellectual disabilities. Classes and tours totalled 725 and 1428 visits respectively. Wally Carter, a wheelchair patient suffering from multiple sclerosis who has worked one day a week for the past six years in the East Access Garden funded by the State Health Department, has now joined the Gardens staff and is funded by a special grant from the Government.

Mrs Susan Wells, Plant Recording Officer, reports a major step forward in recording due to the acquisition of an Apple Macintosh SE computer. Information on the existing 8000+ cards built up since 1983 is being transferred on to computer record along with all new data. Four hundred plant lots (about half the average) have been accessed this year, reflecting lack of space for new plantings and staff shortages. Over two-thirds of the Gardens has been mapped, labelled and recorded, and we now have the reputation of being a well labelled Botanical Garden.

Plant identification work has become an increasingly important aspect of Mrs Wells' work and her position has been upgraded from Technical to Scientific Officer. A new venture has been to utilise the Gardens collection of overseas slides and videos, and local Garden Clubs have shown considerable interest in borrowing these.

Mrs Wells has also edited and produced a new quarterly Gardens Newsletter, a regular news bulletin of current events which has opened up a valuable line of improved communication between all the staff and the Board of Trustees.

Morning, and now evening, guided plant and bird walks in the Gardens were increasingly popular with over 450 attending four walks. Other popular events included an Evening of Music with an audience exceeding 100, other Band Concerts, the Tulip Festival and the Teddy Bears' Picnic.

Professor William Jackson retired from the Board at the end of August having served 28 years as the nominee of the Council of the University of Tasmania. His sterling service to the Gardens was recognised by a presentation made by His Excellency the Governor, General Sir Phillip Bennett, during a luncheon with the Board of Trustees.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, the University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and co-operation.

We are grateful for the dedicated help given by members of the Council during the year, particularly in connection with the Banks Memorial Lectures.

D.R. Gregg
Honorary Secretary

C.A.H. Payne
Senior Vice-President

14 February 1988

THE ROYAL SOCIETY OF TASMANIA

Statement of Receipts and Payments for the year ended 31 December 1988

General Account

Balance 1 January 1988			13 813.02	Stationery			714.49
				Insurance			326.66
Subscriptions				Attendants' fees			86.86
277	@	$12	3 324.00	Secretarial fees			2 543.25
97	@	$ 8	776.00	Post box rental			115.00
20	@	$ 5	100.00	Postage and freight			1 218.37
1	@	$200	200.00	Photocopying			634.14
Other years			680.00	5 080.00	Subscriptions		966.79
					Repairs & maintenance		336.85
Interest				5 522.47	Federal & State duties		124.69
Grants				4 800.00	Telephone		6.00
Donations				8.00	Northern Branch		1 750.00
Sales — publications and					Equipment		1 034.69
Papers and Proceedings				2 687.71	Lecture expenses		171.65
— Banks medals				2 884.00	Refunds		84.00
Investment returns				17 400.00			10 113.44
Macquarie Is. symposium				10 500.00	Macquarie Is. symposium		34 833.30
Banks Memorial Lecture					Tasman Island symposium		1 186.50
Booklet		10 000.00			*Papers & Proceedings*		4 871.50
Travel, lecture		704.91			Banks Memorial Lecture		
Postage		196.45	10 901.36		Booklet	10 307.12	
					Medals	6 555.02	
					Travel, accom. and lecture exp.	2 071.38	18 933.52
							69 938.26
					Balance 31 December 1988		3 658.30
			73 596.56				73 596.56

Accumulation Account

Balance 1 January 1988			79 034.62
Add	Net increase in valuation of publications and medals for sale		11 036.50
			90 071.12
Deduct	Net transfer to Trust Funds	1 942.55	
	Decreased cash at bank	9 194.40	
	Net increase in advance subscriptions	242.00	
	Decreased investments	17 400.00	28 778.95
Balance 31 December 1988			$61 292.17

ROYAL SOCIETY OF TASMANIA
Balance Sheet as at 31 December 1988

1987			*1988*
79 035	Accumulated Funds		61 292.17
84	Subscriptions in advance		326.00
	Trust Funds:		
2 490	— Clive Lord Memorial Fund	2 667.03	
4 172	— A.N. Lewis Memorial Fun	4 486.89	
1 945	— Morton Allport Memorial	2 067.54	
742	— A.A. Clark Bequest	788.79	
5 092	— Joseph Milligan Bequest	5 435.82	
2 774	— R.M. Johnston Memorial Fund	2 952.49	
1 211	— Henry Oliver Bequest	1 292.21	
2 775	— W.H. Hudspeth Memorial	2 963.32	
5 029	— Life Membership Fund	5 509.18	28 173.27
$105 349			$89 791.44
	Represented by:		
33	Cash on hand		33.00
	Cash at bank:		
13 813	— General account		3 658.30
3 362	— *Papers & Proceedings* account		4 013.10
803	— Clive Lord Memorial Fund		931.07
1 114	— A.N. Lewis Memorial Fund		1 295.87
860	Mortgage Loan		860.00
29 900	Commonwealth Treasury Bonds and Inscribed Stock (at cost)		29 500.00
24 000	Interest Bearing Deposits		7 000.00
15 000	Library (at valuation for insurance)		15 000.00
16 464	Publications (at selling prices)		19 820.10
	Medals (at selling price)		7 680.00
$105 349			$89 791.44

The Society owns works of art which have been donated over the years and which do not appear on the Balance Sheet. They are all housed in the Tasmanian Museum and Art Gallery and are covered by that organisation's insurance. A catalogue is available to members listing these works of art.

T.A.H. Knight
Hon. Treasurer

9 February 1989

COMMEMORATING SIR JOSEPH BANKS — SYMBIOSIS AND THE CONCEPT OF MUTUAL BENEFIT

by D. C. Smith

Principal and Vice-Chancellor of the University of Edinburgh,
The Sir Joseph Banks Memorial Lecturer

SMITH, D.C., 1989 (31:x): Commemorating Sir Joseph Banks — Symbiosis and the concept of mutual benefit. The Sir Joseph Banks Memorial Lecture. *Pap. Proc. R. Soc. Tasm.* 123: 1–13. ISSN 0080–4703. University of Edinburgh, Scotland.

Apart from his voyage with Captain Cook, the role of Banks in the founding of Australia owed much to the fact that he was a towering figure in the scientific and national life of late 18th and early 19th-Century Britain. Although he published little of scientific consequence, he achieved a very great deal in helping the scientific endeavours of others and in using his influence with the Government and the King in promoting the cause both of science and of other ventures beneficial to society.

He was President of the Royal Society of London for a record 42 years. Although his Presidency has been criticised in modern times as being autocratic and doing little to improve the Society, this gives a false image of a truly remarkable man whose achievements — Australia apart — were considerable and whose personality was engagingly complex.

It is not easy to assess him as a practising scientist. He published only one serious scientific paper, in which he was the first person to suggest that the Barberry plant can serve as an alternative host to the wheat rust fungus. Although not confirmed by experiment until some 60 years later (by de Bary), this was presumably one of a range of observations which led de Bary to coin the word "symbiosis" for associations (including parasitic) between organisms. Many biologists subsequently restricted the word to only mutualistic associations but a survey of modern knowledge about associations described as "mutualistic" shows that mutual benefit is difficult to define in a way that is experimentally meaningful, and that the concept of mutual benefit should be abandoned.

Although Banks' single scientific paper could, therefore, be said to be an early contribution to symbiosis, he is a classic illustration of the observation that advancement of science depends not only upon those who make original discoveries, but also upon those who select the people and create the conditions under which these discoveries can be made. He differs from many modern civil servants in both having a profound understanding of science and winning the respect of his contemporaries for having this knowledge.

"... a man is never so well employ'd as when he is labouring for the advantage of the Public; without the Expectation, the Hope, or even a wish to derive advantage of any kind from the results of his exertions." — Jos. Banks

BANKS AND CAPTAIN COOK'S FIRST GREAT VOYAGE

In November 1767, the Royal Society of London sent a Memorial to King George III which began:

> "To the King's Most Excellent Majesty. The Memorial of the President, Council and Fellows of the Royal Society of London for improving Natural Knowledge Humbly Sheweth —
> That the passage of the Planet Venus over the Disc of the Sun, which will happen on 3 June in the year 1769, is a Phaenomenon that must, if the same be accurately observed in the proper places, contribute greatly to the improvement of Astronomy on which Navigation so much depends ..."

The Society's memorial continued — rather like a modern research grant application (but in 18th-century language) — with a strong case for support and a proposed plan to send a ship to an appropriate point in the Southern Hemisphere. Finally, the Society estimated the cost at £4000, exclusive of the price of the ship, and concluded its Memorial with almost the same sentiments as it might use today in asking for Government money:

> "The Royal Society are in no condition to defray this Expence, their Annual Income being barely sufficient to carry on the business of the Society."

Contrary, however, to modern practice the Government — or rather the King — responded with speed and generosity. The full £4000 was

rapidly granted, and the Admiralty was instructed to purchase a ship. They acquired a Whitby collier, just under four years old, and "308 tuns burthen". Her name was changed from the *Earl of Pembroke* to the *Endeavour* Bark. A warrant officer, Mr James Cook, was appointed to command it. He was little known outside the navy, but had acquired a considerable reputation within the service as a seaman, navigator and cartographer, especially in naval operations in Newfoundland and Canada. Cook was commissioned Lieutenant in May 1768, and the whole expedition set sail three months later, in August 1768.

Two to three months before the ship set sail, the Royal Society made a further request, which the Admiralty accepted, that

> "Joseph Banks, Esquire, Fellow of this Society, a gentleman of large fortune, who is well versed in Natural History, being desirous of undertaking the same voyage, the Council very earnestly requests their Lordships, that in regard to Banks' great personal merit for the advancement of useful knowledge, he also, together with his suite, being seven persons more (that is eight persons in all) together with their baggage be received on board of the ship under command of Capt. Cook."

Joseph Banks was then 25 years old, an ardent botanist who had been elected a Fellow of the Royal Society two years earlier. He came from a wealthy family of Lincolnshire landowners; his personal income at that time has been estimated to be £6000 per annum. The suite of people he took on board the *Endeavour* included the artist Sydney Parkinson, who was to be immortalised by his beautiful sketches of plants and animals encountered on the voyage, and the botanist Daniel Solander, a pupil of Linnaeus who was to serve as Banks' principal colleague and assistant until his death in 1782.

The presence of Joseph Banks on Cook's first great voyage of discovery was to be of profound significance to the later establishment of the first penal settlement in Australia. He was the first scientist of any consequence to voyage and explore in the Southern Hemisphere. He was already an experienced and avid collector of plants, and this was at a time when great importance was assigned to the discovery of new natural resources in the world, especially plant resources. Throughout Cook's voyage, Banks and his team collected plants voraciously, also making numerous beautiful illustrations of them. About 30 000 specimens were collected, comprising 3600 species, of which 1400 were new to Science — and that at a time when only 6000 species were listed in Linnaeus' *Species Plantarum*.

The original prime purpose of the voyage, observing the transit of Venus, was successfully and very accurately carried out during a stay on Tahiti, an island whose discovery had only been reported a year earlier in 1768. Nevertheless, the three-month sojourn on Tahiti has probably achieved greater historical memorability for the reported beauty and lax morality of the native ladies than for the astronomical observations.

When Cook set out on his voyage, he was given secret orders by the Admiralty. After observing the Transit of Venus on Tahiti, he was "to prosecute the design of making discoveries in the South Pacific Ocean". He was instructed to proceed as far south as latitude 40. If no land was found he was to go west to New Zealand, explore it (to determine whether it was the northern extremity of the Southern Continent), and then return to England "by such route as he thought proper".

In the event he travelled south, encountered no great continent, and sailed to New Zealand which he thoroughly surveyed, circumnavigating it to prove it was two large islands and not part of Terra Incognita. There was then some debate as to which course to take back to England: to return the way they came by way of Cape Horn, or to go directly to the Cape of Good Hope. Neither seemed attractive because it was the depth of winter and the ship was in poor condition. They therefore decided to go by way of the East Indies, looking at the coast that Tasman and other early voyagers had glimpsed a century or more previously and which was then called New Holland. Banks was firmly convinced of the existence of the Southern Continent, but Cook was very doubtful.

In May the following year, 1770, they first set foot on the coast of what we now call Australia. Cook originally called their first landing place Sting Rays Harbour, after an enormous catch of these fish that was made. Later Cook changed the name to Botany Bay because of the "Great quantity of new plants collected in this place".

The role of Joseph Banks in the later development of Australia owes much to the fact that he was later to become the most powerful and influential scientist in England for almost half a century. Upon his return from Cook's voyage, he was accorded the same kind of adulation that might be given today to the first astronaut to return from the moon. It initiated a close and long friendship with the King, a factor that may have been important in his election to the Presidency of the

Royal Society in 1778. The previous President, Sir John Pringle, had earned the serious displeasure of the king in a rather absurd argument over the correct design of lightning conductors, and Fellows may have felt that the next President ought, therefore, to be someone on good terms with the throne. Banks held the Presidency of the Royal Society for a record of 42 years, a period in which he exercised a dominating influence in many spheres. He had a considerable reputation as a savant, being consulted by King and Government on all manner of questions apart from botany, for example: earthquakes, treatment of garden pests, farms, drainage, docks and canals, tanning and currying, the "tricks of millers and bakers" and the plucking of geese.

Banks, however, was well aware that he owed his fame and position very largely to his voyage with Cook. Some 30 years later, in 1813, when trying to persuade the botanist W. J. Hooker to carry out a botanical exploration of Java, he wrote,

> "... I was about 23 when I began my peregrinations. You are somewhat older but you may be assured that if I had listened to a multitude of voices that were raised to dissuade me from my enterprise, I should now have been a quiet country gentleman ignorant of a number of matters I am now acquainted with, and probably have attained no higher rank in life than that of country Justice of the Peace."

BANKS AND THE FOUNDING OF AUSTRALIA

But if Banks derived his influential position primarily from his voyage to New South Wales with Cook, this position was, in its turn, crucial to the founding of the Australian colony. He first publicly advocated Botany Bay as a suitable place to which convicts could be transported in his evidence to a Parliamentary Committee in 1779. At that time, a crisis had arisen in the British Prison System, considerably exacerbated because the American War of Independence had closed off that country as destination for convicts. Alternatives were being urgently considered for distant places to which convicts could be transported. In his evidence, which would carry additional weight since Banks was a highly successful farmer and landowner as well as influential scientist, he waxed enthusiastic about Botany Bay, stressing its good climate, variety of soil, plenitude of fish and water. The passage of time must have sweetened Banks' memory, since what he actually said in his journal when he first saw the bay was:

> "The country tho in general well enough clothd appeared in some places bare: it resembled in my imagination the back of a lean cow, coverd in general with long hair, but nevertheless where her scraggy hip bones have stuck out farther than they ought accidentle rubbs and knocks have intirely bard them of their share of covering."

As the crisis worsened a few years later in 1785, the Government consulted Banks again, and subsequently received a document, the now famous "Heads of a Plan" to colonise the east coast of New South Wales, at or near Botany Bay; this was not signed by Banks, but surely must have at least been drafted by him. It was decisive in causing the Government to choose Australia in preference to the other options then under consideration (which at one time or another had included Senegal, the Gambia and even Gibraltar). The Lords of the Admiralty then rapidly put into operation this plan to send a fleet of convict ships to New South Wales.

Further, as is well known, Banks exerted a profound influence on the early development of the colony, maintaining a voluminous correspondence with the early governors and using his considerable authority to support their pleas to the Government of the day for help. Without his ever-active assistance and agitation behind the scenes, the colony might surely have failed. Even after the colony was firmly established, he maintained his close interest. For example, it was Banks who had a major role in the detailed planning of the famous voyage of Matthew Flinders in the sloop *Investigator*, put together the brilliant team of scientists and artists (including Robert Brown and Ferdinand Bauer), and paid out of his own pocket for the *Investigator* to be well equipped. It was also Banks who nominated Captain Bligh to be Governor of New South Wales in 1805, even specifying the details of his service. The following year saw Banks trying to get the Government to stop the East India Company blocking trade with the new colony.

BANKS AS A SCIENTIST AND AS A PERSON

Banks was a towering figure in the scientific life of late 18th and early 19th-century Britain, but what were his own contributions to the advancement of science? In Sachs' two volume *History of Botany* (1890), Banks merits but a single footnote, and that

PLATE 1

Sir Joseph Banks, portrait engraved by H. Robinson after the painting by Sir Thomas Laurance; published by Harding Lepard, Pall Mall East, London 1831; copy by courtesy of the Allport Library and Museum of Fine Arts, Hobart.

only by way of introducing one of his assistants, Robert Brown, who later became one of the most outstanding botanists of his generation. Such an assessment of Banks is not surprising, since his published works amount to very little. There are some interesting notes in the *Journal of the Royal Horticultural Society* — contributions to the latter including items on how to cultivate the American cranberry and the horticultural management of such plants as the Spanish chestnut tree and the onion; some of his notes, such as that on the forcing-houses of the Romans, reveal him to be a man of culture and learning. Banks was undoubtedly a significant influence in the rise of British horticulture, but in terms of contributions to anything which could be called serious science, there is but a single paper of 23 pages, to be discussed later.

Banks did not even himself publish the results of his epic voyage with Captain Cook: he gave his journal of the voyage (over 200 000 words in length) to a Dr John Hawkesworth who published it under his own name; the magnificent set of engravings of plants collected on the voyage are only being published in their entirety (as the Florilegium) this year, in 1988, the year of the bicentennial, and it was left to others to formally describe the numerous new species that were discovered.

It would be grossly unfair to conclude from this, however, that Banks did not care about publishing the results of important scientific discoveries — rather, it was more the case that he was clearly uninterested in attaching his own name to publications, an engaging aspect of his character which would be incomprehensible to most modern scientists. For example, his own writings show that he passed his journal to Hawkesworth to publish simply because he was busy preparing for a second voyage with Cook on the *Resolution* — a voyage from which he later withdrew because of a disagreement over the adequacy of the accommodation for his scientific needs. Banks had a major role in organising the publication of the illustrations and account of Cook's third voyage but publicly it was Lord Sandwich who gained credit for this.

As for the magnificent illustrations from the first voyage now being published, there is considerable evidence that Banks invested much time and effort towards their preparation and originally had every intention of trying to get them published. Benjamin Franklin reported that Banks employed ten engravers and probably spent at least £4500 on the venture, each plate costing him £6. However, his wealth was not limitless and the heavy expenditure on producing engravings probably coincided with other demands — for example, he had recently got married and was having to pay for the complete refurbishment of his country seat at Revesby Abbey. Also, the American War of Independence probably depressed the income from the wool trade. The sheer size of the effort required probably defeated him in the end. Finally, publication of the illustrations may not have been of overriding importance since the actual plants collected from Australia were meticulously preserved in his personal collections which he made freely available to everyone.

Whatever the reason, it is true to say that Banks' reputation depends almost entirely on what he achieved in the management, organisation and administration of science, rather than on personal publication of novel and important discoveries. His authority derived from a powerful combination of a considerable knowledge of science, friendship with the King and other key figures in England, and his very influential position as President of the Royal Society.

BANKS AND HIS ACHIEVEMENTS

Within the Royal Society, the received opinion of Banks' presidency is not kind to him. He is portrayed as autocratic and doing little to improve the antiquated and sometimes chaotic administration of the Society throughout his 42 years of office. Episodes are still remembered such as the time, early in his Presidency, when he caused the unwilling resignation of the Society's Foreign Secretary, the mathematician Charles Hutton, by making what many thought were contrived accusations of inefficiency against him. At the council meeting when Hutton's resignation was accepted, Banks refused to support the formal vote of thanks for services rendered, on the uncharitable grounds that there was nothing to thank him for. The affair caused much dissension among the Fellows, and pamphlets full of robust hostility to Banks were published. Old wounds were reopened and there was, for example, a pamphlet entitled "An history of the Instances of Exclusion from the Royal Society...and other Instances of the Despotism of Sir J. Banks...and of his incapacity for High Office". It contains many abusive passages about Banks, such as

> "...The President is incurably sick with the lust of domination, he imagines himself born to

rule...and cannot perceive he has neither the intellectual nor the moral qualities of a ruler."

But to take the narrow, "Royal Society" view of Banks would be to have a deeply false image of a truly remarkable man whose achievements — Australia apart — were considerable and whose personality was engagingly complex.

Banks was educated first at Harrow, then at Eton. His school record was unremarkable, but as a teenager at home in Lincolnshire, he suddenly developed a consuming passion for collecting and studying plants. He went up to Christ Church, Oxford, in 1760 to read Botany, but encountered the problem that the Professor of Botany, Humphrey Sibthorp, did not give lectures (or is at least reputed to have given but a single lecture during the entire 35 years in which he occupied the Chair). (When I was the Sibthorpian Professor at Oxford, I was required to give a minimum of 36 lectures in a single year — such has been the nature of academic inflation over the last two centuries.) With Sibthorp's permission, Banks visited Cambridge to hire his own lecturer in Botany, one Israel Lyon, and brought him back to Oxford. After three years at Oxford, Banks left, following the rather common practice of not bothering to take a degree. He moved to London and became a member of a kind of social set of the leading young intellectuals of the day. His passion for collecting plants developed and, instead of following the tradition of his aristocratic contemporaries and going on the Grand Tour, he made a notable trip to Newfoundland and Labrador for the better part of a year. He transformed the knowledge of the vegetation of those countries and gained invaluable experience of how to conduct scientific exploration, learning to endure the physical hardships of working in the field in inclement climates; incidentally it was on this trip that the artist Sydney Parkinson was first initiated into drawing plants.

In 1776, three years after leaving Oxford, Banks became a Fellow of the Royal Society. One might have imagined this was due to his good social standing and personal wealth rather than his scientific interests and discoveries but, although only a minority of Fellows at the time were practising scientists, the signatories to Banks' certificate were not aristocrats but Fellows with serious botanical interests, such as Sir William Watson.

It was his election to the Society (together with his friendship with Lord Sandwich, soon to become First Lord of the Admiralty) which enabled him to fulfil his passion for scientific exploration and get himself attached to Cook's famous voyage. Banks attended the Royal Society Dining Club weekly during the period when the Society was preparing its Memorial to the King, and this must have given him an excellent opportunity to prepare the ground for the Society's later proposal that he be attached to the voyage.

When Banks returned from Australia, he became instantly lionised in society — and to a far greater extent than Cook — but, as his reputation rapidly grew, he was not tempted to indulge in any self-aggrandisement of his personality; instead he began to devote himself wholeheartedly and completely to the cause of science and of scientific institutions. His personal integrity was unimpeachable, and undoubtedly contributed to his influence. For example, later in life some of his detractors scorned his wearing of the ribbon of the Order of the Bath, perpetuated in the portrait by Phillips and the target of a malicious cartoon by Gillray entitled "The great South Sea caterpillar, transformed into a Bath Butterfly". But few also cite the fact that he had refused this coveted Order on an earlier occasion for fear that it would be seen as being tinged with political overtones since, at the time, he was doing his duty as High Sherriff of Lincolnshire and raising troops of militia. Notably, when the King first raised the possibility of this order with Banks in 1789, he made it clear that it was partly for the flourishing state of the Royal Society under Banks' Presidency.

While Banks exercised great and pervasive influence, it is remarkable how often that his efforts resulted in the scientific cause, rather than his own name, achieving prominence. A list of some of his major achievements will illustrate this:

(1) Kew Gardens. He became the scientific adviser to the King (who owned the gardens) in 1773, and in the next 40 years completely transformed them into the gardens we know today. He recruited and sent out, often at his own expense, a series of highly distinguished plant collectors to all parts of the known world to send back the collections which make it the premier botanic garden of the world that we know today. About 7000 species of new exotic plants were added to the garden during his time.

(2) He founded the Royal Horticultural Society, and helped found the African Society (which later became the Royal Geographical Society), being instrumental in organising and financing the expeditions of a number of famous explorers such as Mungo Park and Burkhardt. Banks played a key role in the founding of the Royal Institution, chairing the meeting at which it was inaugurated and dealing sensitively with the temperamental

Count Rumford whose philanthropy triggered its establishment. Likewise, he played a significant role in the events leading to the formation of the Linnean Society, supporting it from his position as President of the Royal Society, although he was not present at the inaugural meeting.

(3) He arranged for Breadfruit to be introduced into the Caribbean. The ill-fated first attempt resulted in the famous Bounty mutiny, but less well known is that the second attempt was so successful that Captain Bligh was voted a reward of £1000 by the House of Assembly in Jamaica. Banks tried to persuade the East India Company to introduce the China tea plant to India, and the area he recommended, Assam, was later to prove ideal for this crop.

(4) In collaboration with the King, he introduced merino sheep from Spain into Britain, resulting in a permanent improvement in the quality of British wool. Initially, Spain prohibited the export of merino sheep, so that Banks had to be a party to organising the smuggling of them out of Spain. Some of these sheep provided stock from which the foundation of the Australian sheep and wool industry developed.

(5) For nearly four decades, he was a dominant figure in the Board of Longitude, a body perhaps as important to improving 18th-century navigation as is NASA to space exploration today. A further illustration of his integrity and passion for defending science occurred when politicians overrode the views of the Board and awarded the prize for a chronometer to a T. Mudge. Banks challenged the Prime Minister (William Pitt):

> "...to rescue Science from the discredit she must fall into if public awards are given to those who have the greatest political interest in preference to those who have most merit."

He also had a long association with the Royal Mint, which began with his management of the Royal Society Cook Medal in 1780 and continued through his involvement in its complete reorganisation, as a member of the Committee of Coins.

(6) Throughout a prolonged period of hostilities with France, he made persistent efforts to ensure that French and British scientists remained in contact and stayed above hostilities. During the War of the French Revolution, for example, the Kingdom of Naples wrongly imprisoned the distinguished French geologist, Dolomieu; Banks made strenuous attempts, in a personal capacity, to obtain his release, lobbying William Pitt, Lord Nelson, Lady Hamilton and others. He also engineered the return to their rightful owners of the important plant collections of the botanists La Billardière and Deschamps, which had been captured from the French. His efforts were long remembered with gratitude in France. Indeed, he was elected an associate of the Institut de France before the Peace of Amiens was signed. Unfortunately, the French immediately published his letter of acceptance before the war was over to show that France had been rehabilitated, and this earned Banks opprobrium from some sections of public opinion who felt he was something of a traitor.

(7) He had a long association with the British Museum, starting with his first reader's ticket in 1764, and ending with his death in 1820, when he ultimately bequeathed his magnificent library, herbarium and other collections to help form the basis for what would later be the Natural History Museum. Throughout his life, he and his various assistants maintained close and detailed contact and collaboration with the Museum.

But perhaps most influential of all was his role as the informal centre of science in this country for four decades. He purchased a large house in Soho Square, London, where his magnificent library and collections were freely available to all reputable scientists. He had a small private staff of librarians and curators, some of whom themselves later became outstanding scientific figures. The latest scientific correspondence and treasures were always on display, there were frequent scientific receptions on Sunday evenings, and his breakfasts were famous informal occasions for meeting guests. Every foreign scientist of note who visited England visited Soho Square. Indeed, Banks and his house fulfilled some of the roles carried out today by International Conferences. Further, much of his personal wealth was channelled into science (and he probably contributed more than the King to the costs of Cook's first voyage). He paid the salaries of quite a number of botanists and plant collectors. For example, he paid George Caley, whom he sent out to make notable collections in Australia, 15/- per week out of his own pocket, since he did not feel he could ask the Government to pay for someone who lacked formal training; later, he even paid Caley, a good collector but a difficult and complaining fellow, a pension of £50 per year. He also paid George Suttor, who was the first successful market gardener and viticulturalist in New South Wales, 15/- per week for collecting, maintaining and transporting out to Australia a variety of fruit trees and other plants. (Just over 100 years later, George Suttor's grandson, Sir

Francis Bathurst Suttor, became the first President of the Sir Joseph Banks Memorial Fund.)

Banks also helped others in a variety of ways. After an angry mob burnt down the house of the chemist Joseph Priestley, it was to Banks that he turned for help in replacing all his chemicals and equipment. In 1782, Banks secured a pension from the King for the astronomer Herschel. (Banks himself made a present of shoes, allowing for seven pairs of socks on cold nights of astronomical observations.) He tried to look after the widows of scientists, lobbying government for a pension for them, or even paying out of his own pocket on some occasions. His benevolence could also be to the country as well as to people. In 1798, the Treasury instructed him to provide such fruit trees, useful plants and seeds as were wanting in His Majesty's colony of New South Wales, but there was no allocation of money and he bore all the expenses himself. He paid for a gift of plants from the King to the Emperor of Russia, and it was three years before the Foreign Office reimbursed him (the dilatory civil servant got a £400 snuff box).

In a sense, therefore, Banks functioned as a kind of one-man benevolent Research Council. Perhaps one of his greatest qualities was his ability to pick first-class scientists as his assistants. Apart from Solander and Robert Brown, they include Dryander, who became librarian of the Royal Society and of the Linnean Society, and others who also became Fellows of the Royal Society, such as Charles Konig and John Sims who founded the Annals of Botany, John Tiarks who left in 1818 to join the American Boundary Commission sponsored by Banks and the Astronomer Royal, and John Lindley who later, in 1838, produced a report which rescued the Royal Botanic Garden at Kew for Science.

BANKS AS A PERSON

While friendship with the famous features prominently in the life of Banks, he was just as kind and caring in his dealings with humbler persons, as witnessed by his copious correspondence with aspiring plant collectors, little-known horticulturalists and seamen with whom he had voyaged.

Indeed, the one area in which he did not receive untarnished success, and curiously the area of which he was most proud, was as the long-serving President of the Royal Society. At the time he assumed office, the Society, like many other British institutions such as the Church and the Universities of Oxford and Cambridge, had sunk into a lethargic state, in need of reform. But the spirit of the age was against reform. One suspects that the episode of Banks engineering the resignation of the Society's Foreign Secretary was a clumsy attempt at reform, and the reaction to it characteristic of the pervasive spirit of resistance to change. Less well publicised were his successful attempts to wrest the nomination and election of Fellows away from the nepotistic influence of the Secretaries. Quite probably, almost anyone else as President would also have found it difficult to carry out major reforms. So, throughout his long Presidency the rules and conduct of business remained antiquated, and the keeping of minutes and the state of accounts remained chaotic. Paradoxically, this was quite out of keeping with all other aspects of Banks' life. He was a meticulous classifier, and his collections, his books, and all matters to do with his busy and extensive estates were quite impeccably organised and filed, likewise his stupendously voluminous correspondence. (It is estimated by some that he wrote 70 000 letters, all in his own hand, during his life, an average of 50 letters a week!) His enemies in the Society may have portrayed him as autocratic but his far more numerous friends respected his firmness, straight-dealing and fairness. There are numerous examples, in the correspondence, of his gift of being able to disagree openly with people on specific issues without in any way impairing his strong friendship with them.

Despite the large amount of letters and other contemporary material concerning Banks, there are aspects of his character that remain enigmatic. His copious writings, including the journal of his voyage with Cook, contain very few comments of a personal nature, so we know very little of his inner thoughts or feelings. One unusual but attractive feature is that he had a dislike of leaving a reputation behind him. At his own express request, he was buried in an unmarked grave in the churchyard at Heston, Middlesex. In a letter to someone who wished to present his portrait to his old college, Christ Church, he wrote that he was "not much addicted to posthumous fame". When selecting his personal seal, he chose the lizard, saying (in his own words)

> "I have taken the lizard, an animal said to be endowed by nature with an instinctive love of mankind, as my device and have caused it to be engraved as my seal, as a perpetual remembrance that a man is never so well employ'd as

> when he is laboring for the advantage of the public; without the Expectation, the Hope, or even a wish to derive advantage of any kind from the result of his Exertions."

This, more than anything else I have read about Banks, epitomises to me his true character; a fitting epitaph to a great and remarkable man.

BANKS AND SYMBIOSIS

The remit I was given for this lecture was to make some assessment of Banks, especially as a scientist, and then to give some account of my own research, which has been in the field of symbiosis. At first sight, there would seem to be absolutely no connection between the life of Joseph Banks 200 years ago and my own interests in biology today, which are in the experimental study of symbiosis.

However, there is a remarkable but convenient coincidence that the one really scientific paper written by Banks concerns an aspect of symbiosis. In 1805, he published a private pamphlet on the diseases of wheat which suggested that the fungus which causes rust disease may be the same as a fungus which also occurs on barberry plants. Over 450 copies were issued, and it was later communicated to the Board of Agriculture. It was also printed in the *Philosophical Magazine, Annals of Botany* and *Journal of Philosophy*. Today it is very well known that the wheat rust fungus has a complex life cycle, alternating between wheat and barberry as hosts, and this knowledge is the basis of a classical method of controlling the disease by eliminating all barberry plants near wheat fields, but when Joseph Banks first put this revolutionary idea in writing, it was attacked by many. Thus, an anonymous reviewer in the *Farmers Magazine*, published in Edinburgh 1805, said,

> "...we are free to say that if the author were not a man of high rank, and at the head of the Royal Society, his publication would be disregarded by every farmer in Great Britain."

In fact the idea was not proven by experiment until the work of German botanist, Anton de Bary, 60 years later. One of the most distinguished 19th-century students of fungi, de Bary was the outstanding expert of his day on fungal diseases of plants and is also well known as the person who invented the term "symbiosis". It was probably his interest in associations between organisms which led him, in 1867, to coin this word to describe organisms which made a common life together, whether as host and parasite or as organisms appearing to derive benefit from associating with each other.

It is the meaning of the word symbiosis and how it is defined which forms the theme for the second part of this lecture. De Bary defined symbiosis simply in the phrase "...des Zusammenlebens ungleichnamiger Organismen..." — the living together of differently named organisms.

However, within a couple of decades of de Bary's original paper, many biologists had come to restrict the term symbiosis to cover only those kinds of association in which all the organisms concerned appeared to derive benefit, and this is the sense in which the word has entered everyday English language. The question to be addressed is whether it is a valid or useful concept in biology that two organisms can live together for their mutual benefit, or whether there ought to be a return to the simple definition of de Bary. If the latter were possible, it would make Banks' one serious scientific paper an early contribution to symbiosis.

An influential factor causing the change in meaning so soon after de Bary invented the word was undoubtedly the discovery of the true nature of lichens a few years before de Bary coined the term symbiosis. For hundreds of years previously, lichens had been regarded as simple plants, and classified as such. Under the microscope, they have a filamentous structure, with a layer of spherical green objects embedded near the surface. These objects were thought to be reproductive spores until, in 1867, the Swiss botanist Simon Schwendener published the revolutionary theory that lichens were not simple plants, but an intimate association of two quite distinct plants, a fungus and an alga (a possibility that de Bary himself had hinted at in an earlier paper). The discovery of the true nature of lichens gave a powerful stimulus to the concept that two organisms could live together for their mutual benefit. It became accepted that there were two kinds of intimate association, parasitic and mutualistic, and most biologists equated symbiosis only with mutualistic associations.

For over half a century afterwards, the nature of the interactions between organisms living together in mutualistic symbiosis was never investigated by rigorous experiment and, during this period, it became embedded in the minds of most biologists that, if an association was termed "symbiotic", then all the partners must derive mutual benefit from the association, even though there was no evidence for this assumption. It is only in the last few decades,

when these interactions have been properly investigated, that it has become clear that "mutual benefit" is a vague concept, difficult to define in a biologically meaningful way, and almost impossible to prove experimentally as occurring in nature. To illustrate the problem I will describe some of the more modern experimental work on mutualistic symbiosis.

LICHENS

The conventional view of the lichen symbiosis which persisted for many years was that the alga supplies the fungus with carbohydrates produced by photosynthesis and that "in return" it was supposed to receive mineral nutrients and some form of physical protection. There is no doubt that the alga does indeed supply the fungus with substantial amounts of photosynthetically produced carbohydrate, and this has been demonstrated by experiments on over 40 different species (Smith 1980).

Much more problematic is whether any nutrients move from fungus to alga. This has never been demonstrated experimentally. In practice, lichen algae grow far more slowly in the lichen than in laboratory culture, hardly an indication of being well nourished. Most of the products of photosynthesis of lichen algae are lost to the fungus instead of being allocated to their own growth, and, again, it is difficult to construe this as "benefit".

Most of the symbionts and their fungal hosts only occur naturally in lichens and hence are mutually dependent on each other, but mutual dependence is not the same as mutual benefit. Many domestic animals are wholly dependent on man for survival; it is a moot question whether such dependence is "beneficial" to them. In the absence of a generally acceptable, rigorous and biologically meaningful definition of the term "benefit", the question remains unanswerable.

ALGA/INVERTEBRATE ASSOCIATIONS: GREEN HYDRA

There are numerous examples of symbioses between algae and aquatic lower invertebrates, ecologically the most important of which are the reef-forming corals, estimated to occupy 90 million km^2 of the earth's surface. However, the symbiosis which has proved most satisfactory for experimental research has been green hydra, an animal which belongs to the same phylum as corals. This coelenterate is widely distributed throughout the world in freshwater habitats. The digestive cells in the endodermis contain a population of about 12–30 cells of the unicellular green alga *Chlorella*, each alga being enclosed in a host membrane. Hydra can be grown in large numbers in controlled laboratory conditions in a simple mineral medium and fed every one or two days on freshly hatched *Artemia* nauplii.

Numerous experiments show that products of photosynthesis move, in the form of the disaccharide maltose, from the alga to the animal host. However, it is equally clear that the host will not grow unless it can also feed, even if it is placed in permanent illumination.

This raises the question of the role of symbiont photosynthesis in the symbiosis. This can be studied directly because, by artificial means, hydra can be freed of their algae, so that host growth with and without algae can be compared. In permanent darkness, green hydra grow more slowly than aposymbionts, showing that symbionts impose a measurable "cost" on the host, presumably deriving nutrients from the host. In the light, green and white hydra grow at the same rate unless the supply of food is reduced to starvation conditions, whereupon green hydra survive much longer. Since food supplies are indeed severely limited in natural habitats (Ellard 1987), it is very likely that the growth of the animal benefits from the presence of algal symbionts.

However, it is very difficult to argue that *Chlorella* "benefit" from the host. In symbiosis, they grow much more slowly than in isolated culture. They lose a considerable amount of carbon to their host, and there is no evidence that they receive a rich nutrient supply from their host; indeed, there is now persuasive evidence that the animal restricts the growth of symbionts to a very low level by severely limiting the supply of nitrogen to them (Rees 1986). *Chlorella* symbionts cannot survive in the wild away from the host, so it is again difficult to see what benefits they derive.

ASSOCIATIONS INVOLVING HIGHER PLANTS AS HOSTS

Mycorrhizas

These are associations between fungi and the roots or other underground organs of green plants. This is probably the commonest type of symbiosis in the world, since the root systems of the great majority of plants are mycorrhizal in natural vegetation. The

fungi involved are mostly incapable of prolonged existence independently from their hosts, but their mycelia often ramify from the root extensively into the surrounding soil, in some respects appearing to function as if they were an extension of the root system.

There are a very large number of pot experiments which show that on nutrient-poor soil, plants infected with mycorrhizal fungi grow more vigorously than uninfected plants, and they also have a higher content of nutrients such as phosphorous and nitrogen; on nutrient rich soils, infection has little or no effect on plant growth or nutrient status. In vesicular arbuscular mycorrhizas, experimental evidence shows that the beneficial effect of infection on host vigour is because the fungal mycelium appears to exploit a greater volume of soil for nutrients than the host root system, these nutrients being transferred to the host plant. There are also many experiments showing that the fungi acquire photosynthetically fixed carbon from their hosts.

Thus, results of simple pot experiments might justifiably be taken as good evidence that the relationship between host and symbiont is "mutually beneficial", host plants "gaining" mineral nutrients in exchange for providing fungi with a carbohydrate source. However, we know very little about interactions in natural vegetation and there are sufficient experimental results to suggest again that relationships between host and symbiont may not be as simple as they seem. In field situations, the soil is densely occupied by root systems of different species. Mycorrhizal fungi have very low specifity, and the same mycelium may frequently interconnect roots of different species. Pot experiments in which the roots of two different plant species are connected by the same fungus show that organic and inorganic nutrients may pass between the plants along the interconnecting mycelia (Francis & Read 1984, Finlay & Read 1986); the receiving plant might thus be considered as parasitic on the donor. Fungal mycelia are more efficient at absorbing mineral nutrients from dilute solutions than roots, so that in soil densely packed with roots, it may be more a question of the fungi "outcompeting" plants for nutrients rather than exploring "unexploited" volumes of soil. Plants gain access to nutrients "sequestered" by the fungus only by mycorrhizal infections, in the course of which they lose photosynthate to the fungus. Experimental evidence on the effect of infection upon the vigour of host plants in the field is very limited, and what there is provides conflicting results (e.g. Fitter 1986).

Leaf nodules

Several genera of plants bear leaf nodules containing bacteria which do not fix nitrogen. The recent study of Miller & Reporter (1987) on leaf nodules of *Dioscorea sansibarensis* deserves particular mention in any consideration of "mutual benefit". *D. sansibarensis* invariably possesses leaf nodules in nature. Plants free of nodules can be produced artificially, and these show depressed vigour compared to nodule-bearing plants; they grow more slowly, leaves are paler and only one is produced per node instead of two. In a straightforward comparison, it appears as if infected plants "benefit" compared to uninfected. The explanation of the apparent "benefit" is obscure. It is not due to nitrogen fixation, and Miller & Reporter suggest the possibility that the bacteria might provide a growth regulator; if this were the case, it presumably replaces the source of regulator provided in the ancestral host plant.

Is it justifiable to describe as "benefit" the improved growth of *D. sansibarensis* caused by bacterial infection in the leaf nodules, especially when those other *Dioscorea* species which do not have leaf nodules have morphologically normal growth? Bacteria and *D. sansibarensis* have become to a large extent mutually *dependent*, but it is difficult to call the relationship mutual *benefit*.

The situation is in some respect reminiscent of Jeon's (1980) work on *Amoeba proteus*. A laboratory culture of this amoeba originally became infected with a pathogenic bacterium which had demonstrably deleterious effects on host growth and survival. Within 200 host generations, the association had evolved to a state where host growth had returned to normal, but the amoeba had become dependent on the bacteria and could not exist without it, probably because the bacteria produced some compound essential to host survival, possibly a protein (Jeon 1980). No measurable *benefit* was conferred on *A. proteus* compared to uninfected cultures, yet bacteria and host had become mutually *dependent*.

SYMBIOSIS AND THE CONCEPT OF MUTUAL BENEFIT

The examples above should illustrate the problems involved in the concept of mutual benefit. The conventional view of symbiosis is that the interactions between the partners are those of conferring benefit, yet it has become quite clear that very often, benefits are accompanied by costs.

For most hosts, benefits seem to outweigh costs, but for many types of symbionts, it could be argued that costs might well outweigh benefits. Also, perceived "benefits" in laboratory experiments may not be so readily manifest in the field.

Nevertheless, there remains a clear difference to many people between symbioses which are termed parasitic and those termed mutualistic. In the former, hosts are undoubtedly harmed in the association because they are exploited by their parasites. In mutualistic associations, it often seems as if the host is exploiting the symbiont.

In the light of these considerations, A.E. Douglas and the author propose a new definition of symbiosis for those associations described as mutualistic, which avoids the concept of mutual benefit yet continues to allow them to be distinguished from parasitic associations. Their definition is

> "Persistent and intimate associations between organisms of different size in which the larger organism (the host) utilises novel or enhanced properties possessed by the smaller partner(s) (symbionts)."

This definition unifies all those associations which are mutualistic, and it is experimentally testable.

SIR JOSEPH BANKS IN RETROSPECT

There is an evident connection, albeit tenuous, between Banks' scientific work and my own interests in symbiosis. The key link is de Bary, who both proved the one major scientific hypothesis which Banks formulated about the life cycle of wheat rust, and coined the term symbiosis to cover situations like fungal diseases of plants.

Banks' single scientific paper was, however, but a tiny fragment of a life devoted to the cause of science. He is a classical illustration of the proposition that advancement of science depends not only upon those who make original discoveries but also upon those who select the people and create the conditions under which these discoveries can be made. He differs from many modern civil servants and administrators in having both a profound understanding of science and the respect of his contemporaries for having this knowledge. He was also fortunate in having sufficient personal wealth and a very good standing in society. At a time when such attributes are the occasional target for social criticism, it is perhaps unfashionable to recall that they can also "confer benefits".

However, it would be unfair and simplistic just to regard Banks' achievements as those of some very superior civil servant. Probably, one of his most important hidden influences was on the subsequent conduct of scientific exploration. He set very high standards for the scientific explorer, not only in how he behaved himself on scientific expeditions but also in the way he insisted on the thorough training of his collectors. Quite possibly, some of the later voyages of scientific exploration owe something to Banks' example.

Finally, there is one ironically beautiful paradox about Banks' life. As we have seen, he did not crave posthumous recognition, he is not remembered for any great scientific discoveries, and he is but a small footnote in the history of botany, the subject he loved. Yet he achieved much in his life, especially in the momentous consequences which his voyage with Captain Cook had for the later settlement of Australia. How fitting, then, that his pioneering work in scientific exploration is commemorated in the naming of over a dozen geographical features around the world, such as bays, capes and inlets. But perhaps the finest tribute is that his name will be remembered forever by that Australian genus of beautiful plants, *Banksia*.

For myself, I remember him most for the quotation that appears at the head of this lecture —

> "...a man is never so well employ'd as when he is labouring for the advantage of the Public; without the Expectation, the Hope, or even a wish to derive advantage of any kind from the results of his exertions." — Jos. Banks

ACKNOWLEDGEMENTS

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BIBLIOGRAPHY

Invaluable sources of information about the life of Sir Joseph Banks were found in the following books (especially that by H. B. Carter), although they are not explicitly quoted in the text.

CAMERON, H. C., 1952: *SIR JOSEPH BANKS K.B., P.R.S. THE AUTOCRAT OF THE PHILOSOPHERS*. Batchworth Press, London: 341 pp.

CARTER, H. B., 1988: *SIR JOSEPH BANKS*. British Museum (Natural History), London: 669 pp.

LYSAGHT, A. M., 1971: *JOSEPH BANKS IN NEWFOUNDLAND AND LABRADOR, 1766: HIS DIARY, MANUSCRIPTS AND COLLECTIONS*. Faber, London: 512 pp.

MAIDEN, J. H., 1909: *SIR JOSEPH BANKS: THE "FATHER OF AUSTRALIA"*. Gullick, Sydney and Kegan Paul, London: 244 pp.

O'BRIAN, P., 1987: *JOSEPH BANKS. A LIFE*. Collins Harvill, London: 328 pp.

REFERENCES

ELLARD, F.M., 1987. Unpubl. D.Phil. thesis, Univ. of Oxford.

FINLAY R.D. & READ, D.J., 1986: The structure and function of the vegetative mycelium of ecto-mycorrhizal plants. I. Translocation between plants interconnected by a common mycelium. *New Phytol.* 103: 143–156.

FITTER, A. H., 1986: Effect of benomyl on leaf phosphorus concentration in alpine grasslands: a test of mycorrhizal benefit. *New Phytol.* 103: 767–776.

FRANCIS, R. & READ, D.J., 1984: Direct transfer of carbon between plants connected by vesicular–arbuscular mycelium. *Nature* 307: 53–56.

JEON, K.W., 1980: Symbiosis of bacteria with *Amoeba*. *In* Cook, C.B., Pappas, P.W. & Rudolph, E.D. (Eds): *CELLULAR INTERACTIONS IN SYMBIOSIS AND PARASITISM*. Ohio State University Press, Columbus, USA: 245–262.

MILLER, I. M. & REPORTER, M., 1987: Bacterial leaf symbiosis in *Dioscorea sansibarensis*: morphology and ultrastructure of the acuminate leaf glands. *Plant, Cell Environ.*10: 413–424.

REES, T.A.V., 1986: The green hydra symbiosis and ammonium. I. The role of the host in ammonium assimilation and its possible regulatory significance. *Proc. Roy. Soc. Ser. B*, 229: 299–314.

REES, T. A. V. & ELLARD, F. M., 1988: The green hydra symbiosis and ammonium. II. Ammonium assimilation and release by freshly isolated symbionts and cultured algae. *Proc. R. Soc. Lond., B* (in the press).

SACHS, JULIUS VON, 1890: *HISTORY OF BOTANY (1530–1860)*. Translated by H. F. Garnsey and revised by Isaac Bayley Balfour. Clarendon Press, Oxford.

SMITH, D.C., 1980: Mechanisms of nutrient movement between lichen symbionts. *In* Cook, C.B., Pappas, P.W. & Rudolph, E.D. (Eds): *CELLULAR INTERACTIONS IN SYMBIOSIS AND PARASITISM*. Ohio State University Press, Columbus, USA: 197–227.

SMITH, D. C. & DOUGLAS, A. E., 1987: *THE BIOLOGY OF SYMBIOSIS*. Edward Arnold, London: 302 pp.

OGURACAULIS BANKSII GEN. ET SP. NOV., A MID-MESOZOIC TREE-FERN STEM FROM TASMANIA, AUSTRALIA

by William D. Tidwell, Harufumi Nishida and Neri Webster

(with one text-figure and five plates)

TIDWELL, W.D., NISHIDA, H. & WEBSTER, N., 1989 (31:x): *Oguracaulis banksii* gen. et sp. nov., a mid-Mesozoic tree-fern stem from Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.* 123: 15–25. ISSN 0080–4703. Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602, USA; The International Budo University, 841 Shinkan, Katsuura City, Chiba 299–52, Japan; and Bicheno, Tasmania, Australia 7215.

Oguracaulis banksii gen. et sp. nov. is described from permineralised specimens from Upper Jurassic–Lower Cretaceous strata near Ida Bay, Tasmania. The specimens consist of large fern stems and adhering petiole bases covered with thick root mantle. Their stems are characterised by a dictyostele with a sclerenchymatous sheath, numerous medullary bundles, an undivided leaf and petiolar vascular trace and multicellular epidermal hairs. This fossil fern provides evidence for the common origin for many of the modern cyatheaceous tree ferns including the cibotioids.
Key Words: Mid-Mesozoic, Tasmania, Cyatheaceae, *Oguracaulis, Cibotium, Angiopteris.*

INTRODUCTION

Permineralised specimens of the tree fern comprising this report, up to 80 mm across by 110 mm long with petiole bases on their surfaces, were collected from strata of either Late Jurassic or Early Cretaceous age at a locality south of Ida Bay in southern Tasmania. This locality lies a few metres to the east and west of South Cape road immediately north of its junction with the Leprena Track. Other plant remains at this locality include species of *Osmundacaulis* (*O. nerii*, Tidwell & Jones 1987, and *O. jonesii*, Tidwell 1987), a fossil tree fern (*Cibotium tasmanense* Gould 1972), fossilised leaf material (Tidwell *et al.* 1987), and as yet undescribed conifer remains.

MATERIALS AND METHODS

The permineralised specimens are incomplete remains from various fern axes. These specimens were collected and donated by Ross Jones of Blackmans Bay, Tasmania, Neri Webster of Bicheno, Tasmania, and Dr M.R. Banks of the University of Tasmania. The specimens were photographed, thin-sectioned and studied. The fossils and their thin-sections provided the basis for morphological comparisons between these specimens and various cyatheaceous forms.

SYSTEMATIC DESCRIPTION

Filicales

Cyatheaceae *sensu* Holttum (1963)
Oguracaulis banksii gen. et sp. nov.
(pls 1–5, fig. 1)

Diagnosis
Fossil tree-fern stem with radial symmetry encircled by persistent petiole bases and adventitious roots; stem vasculature dictyostelic, containing numerous medullary bundles; meristeles surrounded by a sclerenchymatous sheath; tangential cells in phloem; leaf trace omega-shaped with incurved margins and lateral constrictions (omega open adaxially), fusion of medullary bundles forms adaxial arc of leaf trace, undivided throughout; stem surface with multicellular epidermal hairs; numerous adventitious roots arise from stele on each side of leaf trace; roots rarely inside stele.

Generitype
Oguracaulis banksii.

Repository
Tasmanian Museum and Art Gallery Z2286 (holotype), Z2287, Z2288, Z2289, Z2290 (paratypes); Hobart, Tasmania. Brigham Young University 3258 (paratype).

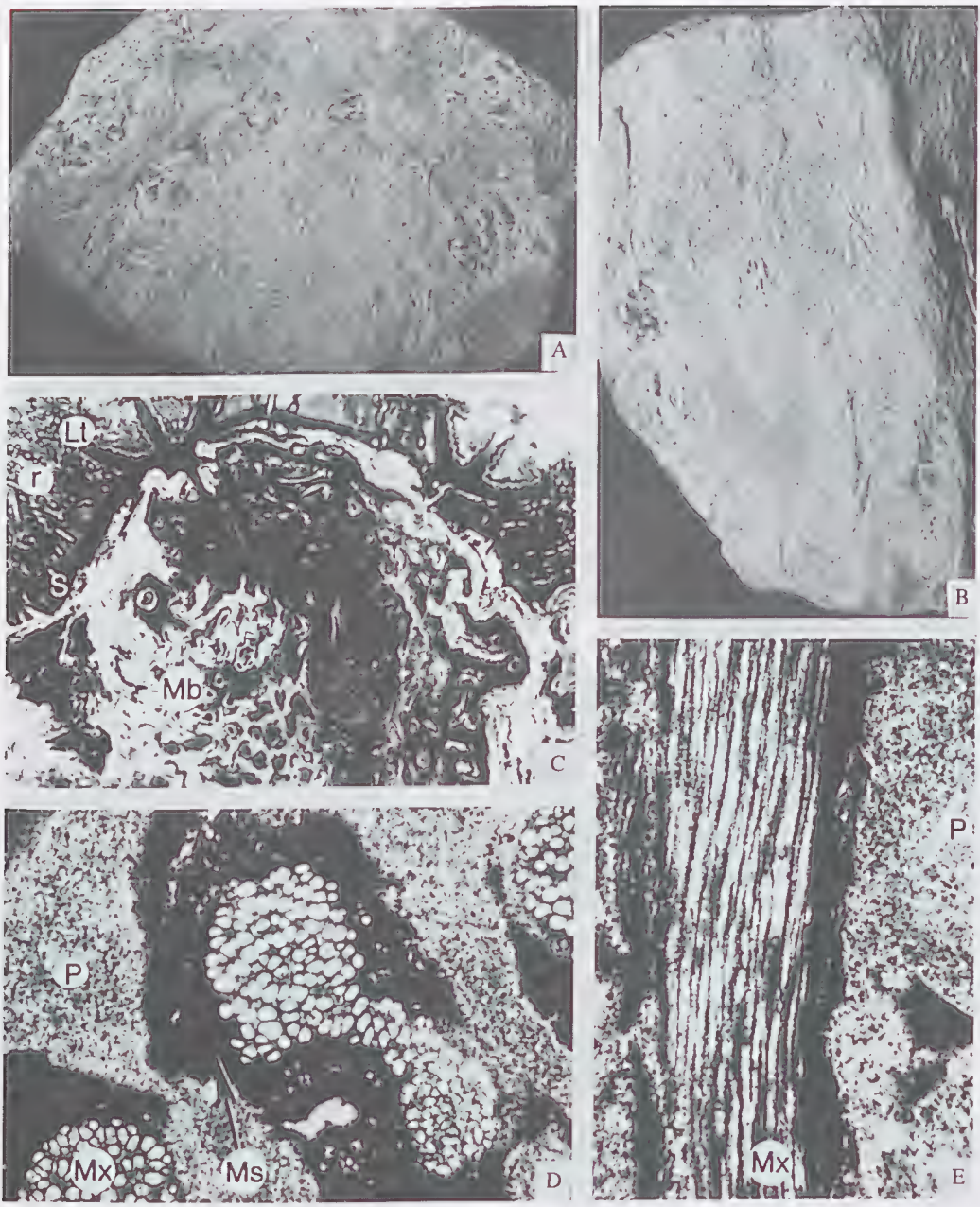

PLATE 1

Oguracaulis banksii *gen. et sp. nov. (A) Top view of holotype Z2286; ×1. (B) Side view of holotype Z2286, note leaf bases and roots on surface; ×1. (C) Cross sectional slide of holotype Z2286; ×1.6. (D) Cross section of medullary bundles, note fusion of bundles, Z2286; ×20. (E) Longitudinal section of a medullary bundle, Z2290; ×20. Stele (S), medullary bundles (Mb), medullary bundles xylem (Mx), roots (R), leaf traces (Lt), medullary bundle sheath (Ms) and pith of stem (P).*

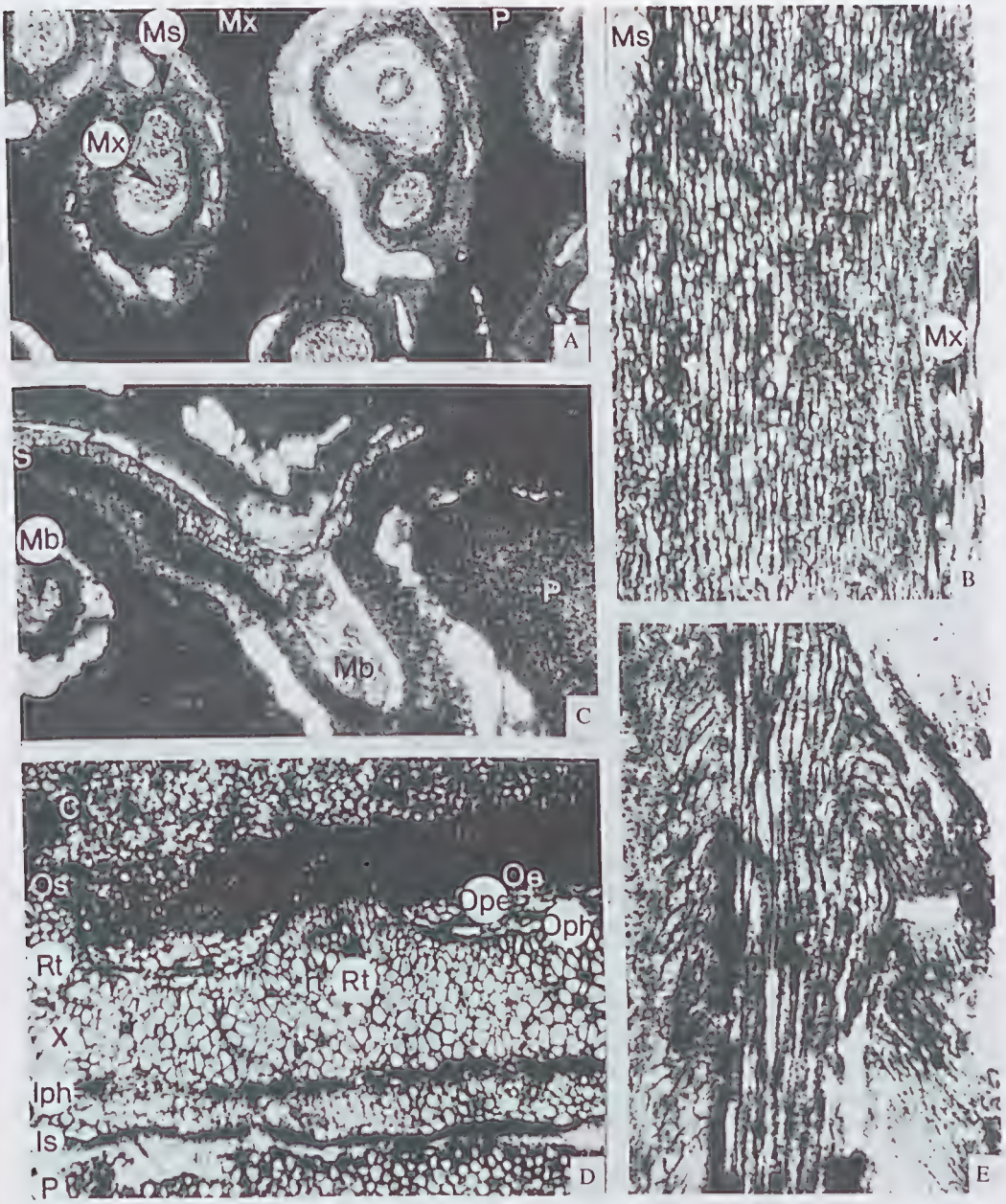

PLATE 2

Oguracaulis banksii *gen. et sp. nov. (A) Cross-sectional view of medullary bundles, Z2286; × 10. (B) Longitudinal section of a medullary bundle, Z2290; × 30. (C) Cross section of stelar strand with an occasional medullary bundle (Mb) connecting with vascular strand, thinner xylem strand to right is the beginning of a trace, Z2286; × 10. (D) Enlarged portion of the stele with two departing root traces, Z2286; × 20. (E) Longitudinal view of xylem strand of the stele with departing root trace, Z2290; × 30. Medullary bundle xylem (Mx), medullary bundle sheath (Ms), xylem (X), inner phloem (Iph), inner pericycle (Ipe), inner endodermis (Ie), inner sclerenchyma sheath (Is), pith (P), outer phloem (Oph), outer pericycle (Ope), outer endodermis (Oe), root trace (Rt), outer sclerenchyma sheath (Os), cortex (C).*

Etymology
The generic name honours Professor Yadzuru Ogura for his many studies on extant and extinct tree ferns, and the specific epithet honours Dr M.R. Banks of the Department of Geology, University of Tasmania, for his assistance with this study and for his interest in the study of fossil plants of Tasmania.

Locality
Near Ida Bay, Tasmania, Australia (Tidwell *et al.* 1987).

Age
Late Jurassic–Early Cretaceous.

Description
The stem of *Oguracaulis banksii* is radially symmetrical, 45–60 mm in diameter, and surrounded by petiole bases (pl. 1A,C). These petiole bases are elliptical in section, up to 30 mm in vertical dimension and 12 mm horizontally (pl. 1B), and are helically arranged in ten orthostichies with each base alternating with those of adjacent rows. Bases of these specimens being separated from each other, their stems having short leaf gaps, and their roots crowding the stems, invading and collapsing their leaf bases, suggest that these specimens are from near the lower portions of older tree ferns.

Leaf scars are visible on the surfaces of the specimens and show the characteristic arrangement of the petiolar vascular strands for this fern. These strands are an unbroken, fluted or corrugated, modified reverse omega (incurved horseshoe) configuration along the periphery of the elliptical petiole bases.

Numerous adventitious roots cover all sides of the specimens and occur between the petiole bases. Many run downward through the specimens. These roots have their origin from the external surface of the stele (pl. 3D,E) and separate from this tissue near the base of the developing leaf trace on each side of the future gap. After departing from the stele, they pass obliquely through the cortex, hypodermis and epidermis, eventually becoming free on the stem surface (pls 1B,4A,5B). They are almost equal in diameter (0.25–1.5 mm) and are diarch, with the xylem elements being surrounded by phloem, pericycle and endodermis (pl. 5D). The cortex of the roots consists of thick-walled fibres and prosenchyma enclosed by a single layered epidermis. Softer tissues are rarely preserved in these structures (pl. 4B) and root hairs were not observed.

Single, unbranched, filamentous hairs arising from the epidermis of the stem are straight and very long, reaching 20-50 mm in length and 1.4 μm in width (pls 4B,5A,B). The multicellular hairs are of the same diameter from their bases with their cells separated by straight septae. The walls of the single row of cells composing these trichomes are thin. The closely-packed hairs are persistent, densely covering the stem surface and extending outward surrounding the roots and petiole bases. Hairs derived from the epidermal cells of the petiole bases are the same as those from the stem.

Beneath the epidermal layer is the hypodermis which is 0.7–2.5 mm wide and sclerenchymatous. This sclerenchymatous layer consists of thick-walled fibrous elements that are 20–25 μm in diameter and 250 μm long.

The cortex is homogeneous and, where preserved, is composed of thick-walled parenchyma cells (30–40 μm in diam.) (pl. 2C,D,E).

The stele is 42–58 mm in diameter, dictyostelic, circular to square in transverse section (pl.1A,C) and appears lobed due to the bulging outward of the leaf traces. It is a hollow cylinder with wall perforated by a few leaf gaps. The stele is variable in thickness, generally 0.5-1.5 mm wide. The amphicribral bundles of the main dictyostele are composed predominantly of xylem with thin layers of phloem, pericycle and endodermis on each side (pl. 3D). The xylem consists of large, angular tracheids with interspersed, smaller, thin-walled xylem parenchyma (pl. 3A). The metaxylem tracheids are variable in size, varying from 40–60 μm in diameter by 1170 μm long. They are radially flattened and have scalariform pitting (pl. 2B). Some distinct protoxylem clusters of 4–6 cells (15–20 μm across) were noted and appear to be mesarch to subendarch.

Compared to the xylem, the phloem is thin (pl. 3A). It is 4–5 cells thick in the inner phloem and 3–4 cells wide in the outer. Sieve cells composing this tissue are 20–30 μm in diameter and tangential cells are present. A several-layered pericycle and a single-layered endodermis occur outside of the phloem. The outer endodermis is prominent, but the inner is obscure. The cells of the inner endodermis are also smaller, 20–30 μm versus 40–70 μm for the outer.

A discontinuous sclerenchymatous sheath occupies the area round the stele and the inner sheath is continuous with the sclerenchyma masses surrounding the adjacent medullary bundles. Therefore, the face of the sheath towards the pith is irregular in outline due to the numerous medullary

bundles of the pith, whereas the stelar side of the sheath is regular.

In these fossil specimens, 300–350 medullary bundles are scattered throughout the pith (pls 1A,C–E,3A,C,4A,B,E). They vary in size (0.5–2.5 mm) and shape, and occur in clusters. The bundles are closely packed in the pith, which causes distortion in their shape. They are circular to elliptical in outline, often containing a flattened string of tracheids (pl. 1D). Sometimes bundles divide or fuse together to form a network, resulting in an elliptical shape or an elongated chain. These medullary bundles are usually protostelic, with an occasional bundle having parenchyma in the centre of the xylem. Softer tissues, which are often not well preserved, surround the xylem. In some specimens a black line (probably degraded protophloem), a pericycle 1–2 cells wide, and an endodermis with Casparian thickenings can be observed. A thin space between the black line and the xylem corresponds to the metaphloem. Outside of the endodermis is a ring of sclerenchymatous tissue of varying shape and thickness. The sclerenchymatous ring corresponds to the sclerenchymatous sheath of the stele and has the same general structure. Occasionally bundles fuse with the main stelar structure.

Although parenchymatous tissue may also be present in the pith, the major portion of the pith consists of a network of sclerenchyma (pl. 2A). Thus, the medullary bundles appear to be enclosed by double sheath-layers, of which the outer is parenchymatous and the inner sclerenchymatous. There are no mucilage cells in the fundamental tissues.

The boundary between the leaf gap, the stem vascular bundle and the leaf trace is indistinct. The position of the developing leaf trace can be noted where the xylem strand of the main stelar ring is only one to three tracheids thick (pl. 3C). Upward this section of the strand expands outward as a rounded protrusion to form the abaxial portion of the beginning leaf trace (fig. 1). The beginning trace gradually enlarges into the cortex, forming the abaxial arc of the typical cyatheaceous petiole vascular pattern (pl. 4A; Nishida 1984). Two circular medullary bundles that are side by side generally appear in the bulge (fig. 1A). Two more medullary bundles elongate into the forming gap and ultimately fuse with the previous two bundles. As they fuse, these bundles develop hooks at their tips (fig. 1B,C). Enlarging outward, the beginning trace remains as a semicircular, continuous band. This structure eventually becomes wavy, resulting in a fluted or corrugated structure. Protoxylem

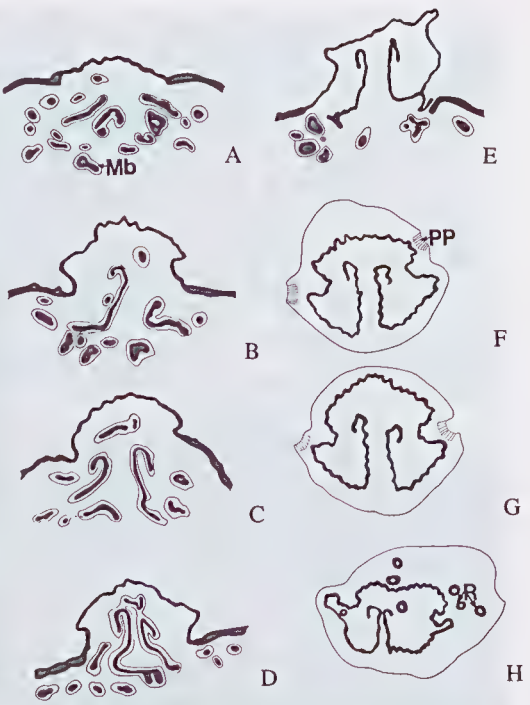

FIG. 1A-H — Oguracaulis banksii *gen. et sp. nov. Various stages in the development of a leaf trace, medullary bundles (Mb), roots (R), possible pneumathode (Pp);* × *1.66.*

points occur at the outer projection of each bend of the fluted trace. The elongated medullary bundles fuse with the adaxial part of the trace to form a pair of adaxial arms of the petiole vascular bundle (fig. 1F). The trace then separates from the main stele of the stem, leaving a leaf gap (fig. 1F; pls 1C,4A,C). A pair of shallow lateral constrictions are developed in the leaf trace. In some petiole bases, a pair of medullary bundles remain in the pith, isolated from the continuous omega-shape of the standard leaf trace. These traces soon disappear distally in the petiole. Medullary bundles occasionally fuse with the gap end of the vascular strands of the stele immediately upon departure of the leaf trace (pl. 3C). This gives the impression that the vascular strands turn pithward on at least one, sometimes both, sides of the gap. The strands soon approach each other and finally the gap is closed. The trace becomes enclosed with part of the sclerenchymatous sheath of the xylem and the hypodermis as it progresses through these tissues of the stem. The sclerotic tissue of the petiole is

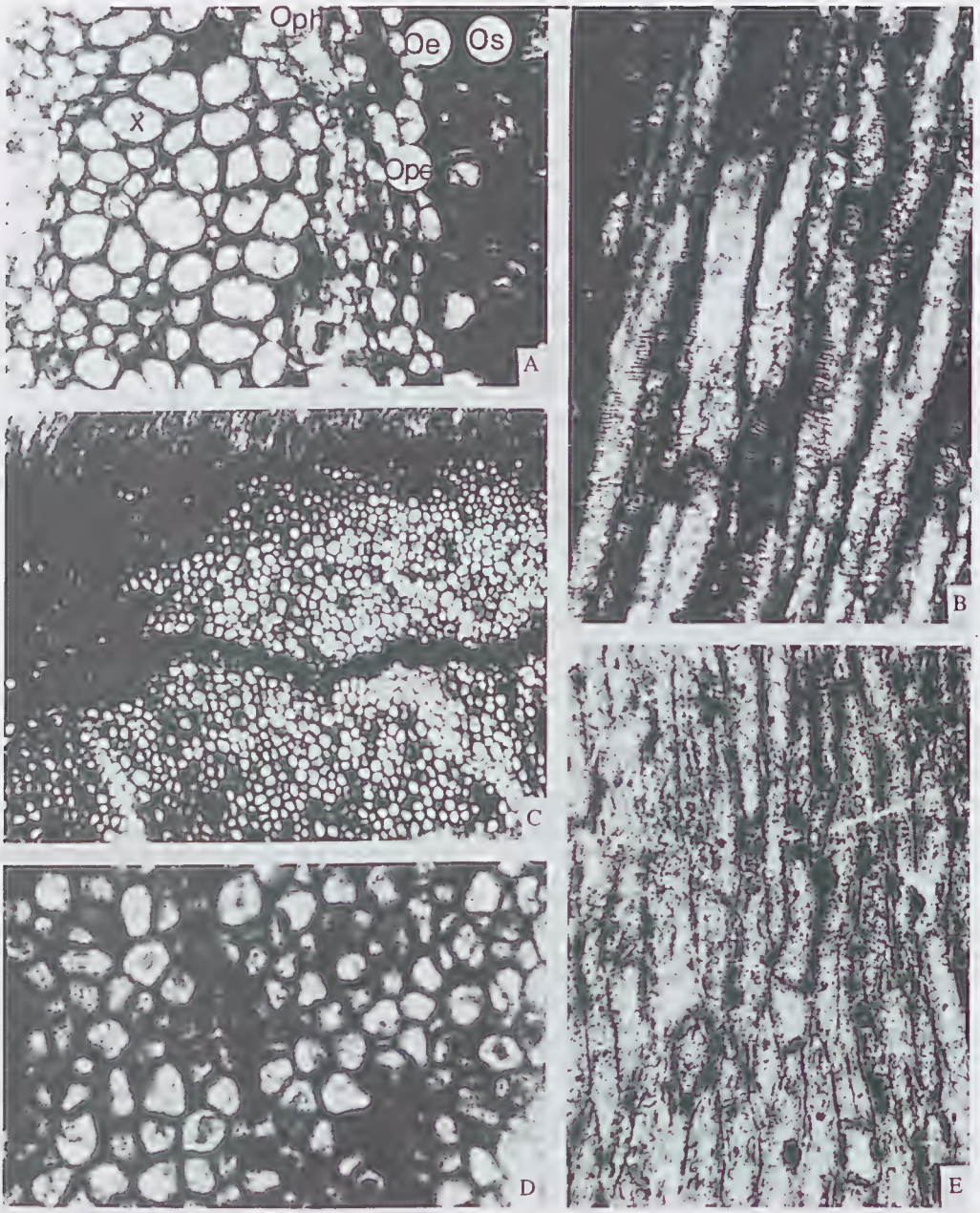

PLATE 3

Oguracaulis banksii *gen. et sp. nov. (A) Closeup of xylem (X), outer phloem (Oph), outer pericycle (Ope), outer endodermis (Oe) and outer (external) sclerenchyma sheath (Os); Z2286; ×60. (B) Longitudinal section of xylem strand, note scalariform thickenings on the tracheid walls, Z2240; ×60. (C) Cortex, Z2286; ×33. (D) Closeup of cells of the cortex, Z2286; ×90. (E) Longitudinal view of the cortex, Z2290; ×90.*

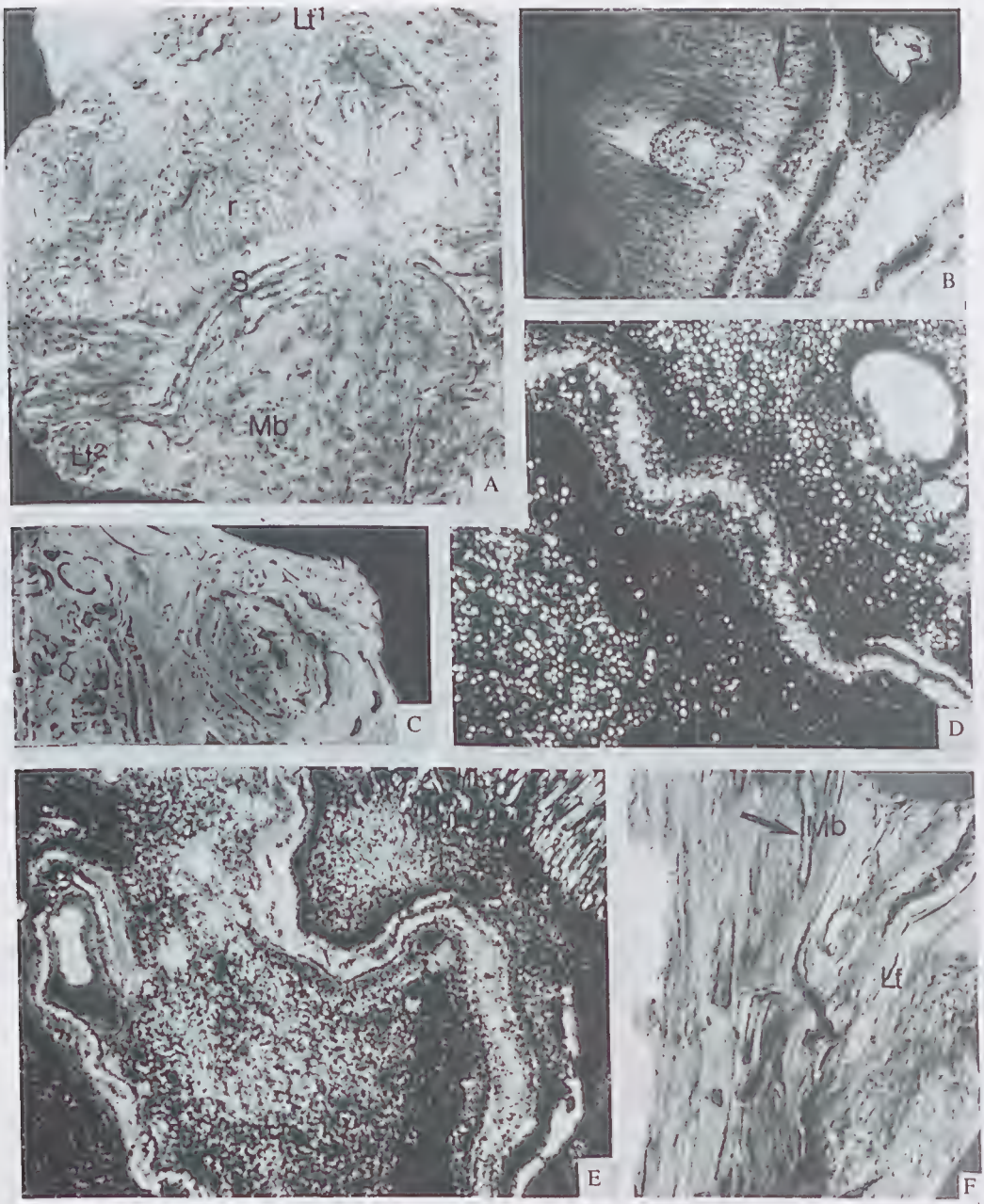

PLATE 4

Oguracaulis banksii *gen. et sp. nov. (A) Specimen showing a leaf trace (Lt[1]), a forming leaf trace (Lt[2]) and roots (R), note medullary bundles (Mb) inside the stele (S), Z2287; ×2. (B) Cross section of cortex with attached epidermal hair (arrow) surrounding roots, Z2286; ×10. (C) Cross section of specimen with leaf trace, note characteristic shape, Z2288; ×1. (D) Closeup of vascular strand of a leaf trace, Z2286; ×20. (E) Part of a leaf trace, note the possible pneumathode at upper right, Z2286; ×12. (F) Specimen showing leaf trace (Lt) departing the stele, medullary bundles (Mb), Z2289; ×1.4.*

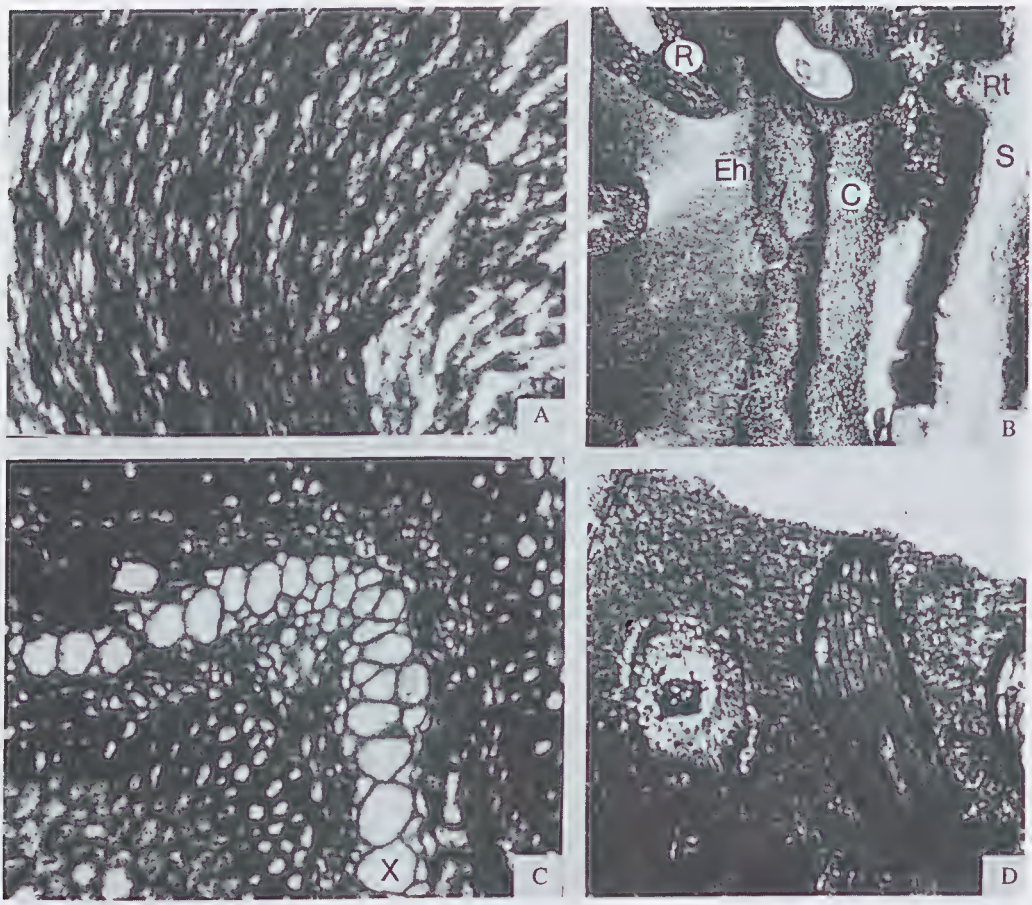

PLATE 5

Oguracaulis banksii *gen. et sp. nov. (A) Closeup of epidermal hair, Z2286; ×90. (B) Stelar strand (S), cortex (C) and epidermal hair (Eh), note departing root traces (Rt) and roots (R), Z2286; ×10. (C) Closeup of xylem of a leaf trace, Z2286; ×60. (D) Cross- and longitudinal sections of roots, Z2286; ×15.*

interrupted laterally by possible pneumathodes (pl. 4E; Williams 1925).

Petioles in transverse section vary in shape from circular to elliptical with lateral grooves (fig. 1F–H). They arise at a steep angle (10–20°) to the stem (pl. 4F) and vary in size from 10 mm in the cortex to 12 x 30 mm toward the outside of the specimen.

The vascular strand of the petiole is bisymmetrical, U-shaped with incurved ends. The U of the trace is adaxially open and has lateral constrictions on each side, resulting in a modified reverse omega-shape (pl. 4D,E).

A single layer of cells with attached uniseriate, multicellular hairs constitutes the petiolar epidermis. The hypodermis of this structure consists of a uniform layer of sclerenchyma. There is a gradual transition from hypodermis to the cortex. Cells of the latter tissue vary in size. The sheath surrounding the vascular strand appears to be two-layered with the outer layer composed of fibrous cells and the inner parenchymatous. An endodermis and a pericycle of several layers lie inside the sheath. The layer of protophloem is thin, discontinuous and not very distinctive. The outer metaphloem, composed of sieve cells and

parenchyma, is one to several layers thick and has larger cells than the inner metaphloem which is generally difficult to distinguish. Large mucilage cells, 97–150 µm in diameter and containing dark brown substances, are present in the external phloem. Xylem strand is continuous and wavy with protoxylem occurring on the inner portion of the outer projection of the strand.

COMPARISONS AND DISCUSSION

Oguracaulis banksii is characterised by having a radially symmetrical stem with dictyostelic main stelar ring, undivided leaf and petiolar vascular traces, an internal and external sclerenchymatous sheath, numerous irregular, anastomosing, medullary bundles, some of which form the adaxial arcs of the petiolar vascular strand, epidermal hairs and tangential cells in its phloem.

White (1986) preliminarily compared specimens of *O. banksii* with *Angiopteris*. *Oguracaulis*, however, differs from *Angiopteris* in having (1) a well-developed sclerenchyma sheath around the vascular bundles, (2) a less dissected dictyostele (Tansley 1907), (3) a continuous omega-shaped petiole trace composed of a wavy vascular bundle, and (4) V-shaped units of vascular bundles enclosed by a complete endodermis. These features are lacking in *Angiopteris*.

Cyatheaceae is the family with stems most similar in structure to this fossil tree fern. Generally, this family exhibits a typical arborescent habit. Its members are distributed in both the palaeo- and neotropics, particularly in moist, temperate mountain regions (Holttum 1963, Tyron 1970). The Cyatheaceae has been variously classified by different authors into one or two or more families (see discussion by Holttum 1963, Tyron 1970, Lucansky 1974a,b, Lucansky & White 1974, Nishida 1984). In the general classification of the Cyatheaceae as a single family and its subdivisions, we have followed Holttum (1963).

Oguracaulis banksii is most closely comparable to species of the Cibotioideae and Cyatheoideae of the Cyatheaceae. The cibotioids, including *C. tasmanense* Gould (1972) from this Tasmanian locality, differ from *O. banksii* in generally having a lateral discontinuity in their petiole vasculature and in lacking medullary bundles and stelar parenchyma (Williams 1925, Ogura 1930, Barrington 1983) that occur in the fossil form. Most living members of the squamate cyatheoids are anatomically similar to *O. banksii* but can be distinguished from it principally by their leaf traces being formed of a series of traces and their possessing dermal scales rather than hairs (Ogura 1927, 1938). *Metaxya* and *Lophosoria*, also of the Cyatheaceae (Lucansky 1974a, 1982), are similar to the fossil but differ from it mainly in their lack of medullary bundles.

The Thyrsopteridoideae, consisting of *Thyrsopteris* and *Culcita* (Holttum & Sen 1961) shares very few characters with *O. banksii*. They differ in the structure of their medullary bundles, the way these bundles contribute to petiole vascularisation (Bower 1913, Sen 1968) and the clear lateral discontinuity in their petiole vasculature. Both *Thyrsopteris* and *Culcita* lack the numerous medullary bundles that occur in *O. banksii*.

Cyathocaulis and *Cyathorachis*, from the Cretaceous of Japan, Korea and the Philippines, may be the only representatives of or, at least, closely related to the ancestors of the squamate cyatheoids (Ogura 1941, Nishida 1981, 1984, Nishida & Tanaka 1982). *Cyathocaulis* has hairs similar to *O. banksii*, but differs from the latter in having a number of medullary roots in its dictyostelic stem and leaf traces that consist of many individual traces.

Dendropteridium cyatheoides Bancroft (1932), *Alsophilocaulis calveloi* Menendez (1961) and *Cyathodendron texanum* Arnold (1945) of Tertiary age are similar to *Cyathea* and therefore unlike *O. banksii*.

Lophosoriorhachis japonica H. Nishida (1982) is a fossil rachis of uncertain affinity. Hair-like structures are present on the surface of *L. japonica* (Nishida 1984), and its vasculature is a continuous corrugated horseshoe-shaped structure with lateral folds and incurved margins similar to those in *O. banksii*. *Oguracaulis banksii* differs from *L. japonica* by having a much longer median pair in its petiolar vascular trace and in lacking large mucilage cells in its fundamental tissue.

Leaves and sori of *O. banksii* are unknown. Although dicksonioid in appearance, *Coniopteris websterii* Tidwell, Kim and Kimura from this locality cannot be assigned to any of the anatomically preserved taxa from this site.

Oguracaulis is important in considering the evolution of the scaly cyatheoids. *Oguracaulis*, the *Cyathocaulis* group of the Cretaceous and recent scaly cyatheoids appear to comprise a morphological sequence from primitive to advanced respectively. A Late Jurassic to Early Cretaceous age for *Oguracaulis* chronologically fits well into this sequence. The dermal hairs, stelar pattern and undivided leaf traces of *Oguracaulis*, however, are

features similar to the primitive genera *Metaxya* and *Lophosoria* of the Cyatheoideae, as well as members of the Cibotioideae. Based upon this comparative anatomical data, *Oguracaulis banksii* appears to be a new, relatively primitive genus and species in the Cyatheaceae.

The presence of *Cibotium tasmanense* Gould in the same locality as *O. banksii* indicates cibotioid tree ferns also occurred at the same geologic time. *Oguracaulis banksii* lacks the long adaxial arcs of the leaf trace which are characteristic of *Cibotium*. Ferns with this characteristic are known as early as the Late Cretaceous (Nishida 1984). Since *C. tasmanense* was first described as Tertiary in age and having an internal structure too primitive to be assigned to *Cibotium*, Nishida (1984) doubted its affinity with *Cibotium*. The geologic age of this material has, nevertheless, been reconsidered and assigned to a Late Jurassic or Early Cretaceous age (White 1986, Tidwell *et al.* 1987), which is older than the oldest permineralised stem that definitely belongs to *Cibotium* (*Cibotium iwatense* Ogura, Coniacian-Santonian). *Cibotium tasmanense* is, therefore, a possible ancestral form of *Cibotium*. This, and the possible relationship of *Oguracaulis* with the squamate cyatheoids, suggest that the cyatheaceous tree ferns were diversified by the Late Jurassic or Early Cretaceous.

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REFERENCES

Arnold, C.A., 1945: Silicified plant remains from the Mesozoic and Tertiary of western North America. I. Ferns. *Mich. Acad. Sci., Arts, Lett. Pap.* (1944) 30: 3–34.

Bancroft, H., 1932: A fossil cyatheoid stem from Mount Elgon, East Africa. *New Phytol.* 31: 241–253.

Barrington, D.S., 1983: *Cibotium oregonense*: An Eocene tree-fern stem and petioles with internal structure. *Amer. J. Bot.* 70: 1118–1124.

Bower, F.O., 1913: Studies in the phylogeny of the Filicales. III. On *Metaxya* and certain other relatively primitive ferns. *Ann. Bot.* 27: 443–447.

Gould, R., 1972: *Cibotium tasmanense* sp. nov., a fossil tree-fern from the Tertiary of Tasmania. *Aust. J. Bot.* 20: 119–126.

Holttum, R.E., 1963: Cyatheaceae. *Flora Malesiana II* 1(2): 65–176.

Holttum, R.E. & Sen, U., 1961: Morphology and classifications of the tree ferns. *Phytomorphology* II(4): 406–420.

Lucansky, T.W., 1974a: Comparative studies of nodal and vascular anatomy in the neotropical Cyatheaceae I. *Metaxya* and *Lophosoria*. *Amer. J. Bot.* 61: 464–471.

Lucansky, T.W., 1974b: Comparative studies of nodal and vascular anatomy in the neotropical Cyatheaceae II. Squamate genera. *Amer. J. Bot.* 61: 472–480.

Lucansky, T.W., 1982: Anatomical studies of the neotropical Cyatheaceae. II. *Metaxya* and *Lophosoria*. *Amer. Fern J.* 72: 19–29.

Lucansky, T.W. & White, R.A., 1974: Comparative studies of the nodal and vascular anatomy in the neotropical Cyatheaceae. III. Nodal and petiole patterns; summary and conclusions. *Amer. Fern J.* 61: 818–828.

Menendez, C.A., 1961: Estipite petrificado de una neuva Cyatheaceae del Terciario de Neuquen. *Bol. Soc. Arg. Bot.* 9: 331–358.

Nishida, H., 1981: A revision of the genus Cyathorachis in Japan. *Bot. Mag. Tokyo* 94: 249–259.

Nishida, H., 1982: *Lophosoriorhachis japonica* n. gen. et sp., from the Lower Cretaceous of Choshi, Chiba Prefecture, Japan. *Palaeontographica* Abt. 181B: 118–122.

Nishida, H., 1984: Anatomical studies of the frond axis of the Cyatheaceae, s. l. with a revision of permineralized frond axes from the Cretaceous of Japan. *CONTRIBUTIONS TO THE BOTANY IN THE ANDES*. Vol.1. Academia Scientific Book Inc., Tokyo: 5–80.

Nishida, H. & Tanaka, K., 1982: Anatomical studies of *Cyathocaulis naktongensis* Ogura from central Honshu, Japan. *Bull. Natl Sci. Mus., Ser. C (Geol. Paleont.)* 8: 19–30.

Ogura, Y., 1927: Comparative anatomy of Japanese Cyatheaceae. *J. Fac. Sci. Imp. Univ. Tokyo, Bot.* 1: 141–350.

Ogura, Y., 1930: On the structure of Hawaiian tree ferns, with notes on affinity of *Cibotium*. *Bot. Mag. Tokyo* 44: 467–479.

Ogura, Y., 1938: *HANDBUCH DER PFLANZEN-ANATOMIE. ANATOMIE DER VEGETATIONS-ORGANE DER PTERIDOPHYTEN*. Band IV. 2. Teil. Gebrüder Borntraeger, Berlin.

Ogura, Y., 1941: On the structure of a fossil tree fern from Mindoro, Philippine Islands. *Jubl. Publ. Prof. Yabe; Contrib. Bot. Inst. Fac. Sci. Tokyo Imp. Univ.* 241: 911–917.

Sen, U., 1968: Anatomy of *Culcita macrocarpa*. *Can. J. Bot.* 46: 43–46.

Tansley, A.G., 1907: Lectures on the evolution of the filicinean vascular system, VII. Polycycly. *New Phytol.* 6(9): 219–238.

Tidwell, W.D., 1987: A new species of *Osmundacaulis* (*O. jonesii* sp. nov.) from Tasmania, Australia. *Rev. Paleob. Palynol.* 52: 205–216.

Tidwell, W.D. & Jones, R., 1987: *Osmundacaulis nerii*, a new osmundaceous species from Tasmania, Australia. *Palaeontographica* 204B: 181–191.

Tidwell, W.D., Kim, J.K. & Kimura, T., 1987: Mid-Mesozoic leaves from near Ida Bay, southeast Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.* 121: 159–170.

Tyron, R., 1970: The classification of the Cyatheaceae. *Contrib. Gray Herb. Harv. Univ.* 200: 1–53.

White, M., 1986: *THE GREENING OF GONDWANA*. Reeds Books, Frenchs Forest, Australia.

Williams, S., 1925: Some points on the anatomy of *Dicksonia*. *Proc. R. Soc. Edinb.* 45: 286–296.

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ARCHAEOLOGY OF THE OLD ICEWORKS, 35 HUNTER STREET, HOBART

by Angela McGowan

(with one table, one text-figure and four plates)

McGOWAN, A.E., 1989 (31:x): Archaeology of the Old Iceworks, 35 Hunter Street, Hobart. *Pap. Proc. R. Soc. Tasm.* 123: 27–36. ISSN 0080–4703. Department of Lands, Parks and Wildlife, GPO Box 44A, Hobart, Tasmania, Australia 7001; formerly Anthropology Department, Tasmanian Museum and Art Gallery.

The invention and development of refrigeration technology in the second half of the 19th century was a crucial factor in the success of Australia's meat export trade, although in Tasmania it was the fruit trade which made the most use of it. The Henry Jones Iceworks and cold-storage facility at 35 Hunter Street, Hobart, was probably established in 1903, involving extensive alterations to the existing building. Six of the seven insulated rooms in the building still contained refrigerant piping in 1986. This represented about one-twentieth of the volume of the original facility and was mostly used for cold storage. However, there is also evidence that most, if not all of the firm's ice-making took place on this site. The "Old Iceworks" was an important component of the industrial and commercial development of Hobart. Its remains were representative of refrigerating technology and equipment found throughout Australia in the early 20th century and were the last surviving ammonia iceworks in Tasmania.
Key Words: ice-making, cold storage, historical archaeology, Hobart, Tasmania.

INTRODUCTION

In July 1986, the Old Iceworks building at 35 Hunter Street, Hobart, was declared unsafe and the Department of Construction Tasmania decided to demolish it, except for its facade. Following this decision, the Tasmanian Museum and Art Gallery was asked to determine the cultural significance of any equipment remaining in the building.

Some investigation of the historical and archaeological significance of the site was made by a team consisting of the author and Vicki Pearce from the Tasmanian Museum and Art Gallery, and Richard Morrison from the National Parks and Wildlife Service. A report on the quantity and availability of relevant historical documentation was prepared by Vicki Pearce (1986). In addition to the sources consulted, the records of Henry Jones IXL are held by the Melbourne University archives. Permission has been obtained from Elders IXL Ltd for the Museum to gain access to these records, which would be essential to a full interpretation and understanding of the site, but their location in Melbourne has prevented their being examined so far. Richard Morrison arranged for a photogrammetric survey of the building's exterior to be undertaken by officers of the Hydro-Electric Commission. The author prepared a preliminary archaeological report which dealt primarily with the remains of ice-making and cold-storage equipment still extant (McGowan 1986).

The building was part of the ice-making and cold-storage facility operated by the jam-making firm of Henry Jones (IXL) from around the turn of the century until the 1970's. Ice was also supplied to the public here. The building, with the exception of its front facade, was demolished in January 1987.

THE SIGNIFICANCE OF COLD STORAGE IN AUSTRALIA'S INDUSTRIAL HISTORY

Farrer (1980: 183–200) discusses the invention and development of refrigeration technology and its significance for Australian trade. Prior to the invention of refrigeration, food was chilled for preservation by means of natural ice. Australia imported blocks of river ice from Canada for use in ice-boxes. However, it was not until the development of mechanical refrigeration that long-term cold storage became reliable and widely accessible.

In the second half of the 19th century, Australia was a world leader in refrigeration technology. James Harrison of Bendigo made the world's first practicable ice-making machine in 1851. He made ice for the somewhat limited local market and later that year a Melbourne brewery installed a machine of its own. In the 1860's, the implications of the invention for the meat export industry were

realised, although it was nearly 20 years before the technology was sufficiently developed to allow frozen meat exports to the United Kingdom. Canada and the United States were packing meat for export to Europe with natural ice, which was easily adequate for the short Atlantic crossing, especially in winter. However, Australian exporters were faced with a much longer journey passing through the tropics. Spurred on by the commercial need to export meat to Britain without loss of quality, various technological improvements took place in Australia in the 1870's, in an atmosphere of intense commercial rivalry and competition (Farrer 1980: 185–188). In 1875, Thomas Mort and Eugene Nicolle opened refrigerated warehouses in Sydney and used refrigeration in the transport and storage of milk and meat from country New South Wales (Farrer 1980: 190). Despite the technical success of the refrigerated sea voyages in the 1880's and 1890's, the appearance of the frozen meat was not acceptable to the customers' taste and this trade declined rapidly after the boom years of the 1890's (Farrer 1980: 258—graph).

However, it was not only the meat that required refrigerated transport. The fruit trade began exporting apples from Tasmania to London in 1884 (Anon. 1899: 387). Initially losses were incurred due to the poor condition of the fruit on its arrival. Tasmania's chief rivals for the London market were Canada and the United States of America. By 1899, cool-storage facilities had been available in those countries for a couple of years, allowing apples to be stored and exported to Europe as required. Tasmania, on the other hand, was forced to export its produce as soon as it was harvested. This meant that Tasmanian producers could not take advantage of fluctuations in the European market and often found themselves competing against cheaper local produce (Anon. 1899: 387–389). Initially Tasmanian fruit was sent via Melbourne, but the extension of refrigerated shipping to Hobart, in 1899, allowed Tasmanian fruit producers to export directly to London, thus reducing some of their costs. However, competition from North America still seriously affected the profitability of the Tasmanian industry. Linge (1979: 646) attributes the eventual success of the Tasmanian industry to cheaper shipping costs, but it is unlikely that full advantage of the reduction could be taken until the provision of cold-storage facilities in Hobart allowed producers the choice of timing their exports. Therefore, it was the introduction of these facilities for the fruit trade which allowed Tasmanian producers to regain their competitive edge in the world's markets.

By the 1930's, a number of cool chambers and cold-storage facilities existed in Tasmania at both Hobart and Launceston. These were used for chilling meat, storing fruit and in the brewing industry. Messrs J. Boag & Son built cool chambers shortly before 1931 to keep their Esk Brewery in Launceston up to date. Bender and Co. Pty Ltd built the first cool store in northern Tasmania at Brisbane Street in Launceston and had another cool store in Hobart at Elizabeth Street; these were used to chill fruit prior to export and smallgoods, and as commercial cold-storage facilities. Also, H. Dunn installed "special chilling chambers" at his butchers premises in Elizabeth Street, Hobart (Anon. 1931: 204, 320, 324).

The provision of cold storage was also significant in the local economy. Most 20th-century freezing works in Launceston and Hobart were established by local businesses primarily to store their own perishable goods. These facilities quickly became important to other small entrepreneurs such as people supplementing their living through rabbit-catching (e.g. *The Weekly Courier* 16 May 1903 and *The Tasmanian Mail* 6 June 1903).

Meat and dairy produce in Australia and France, fish in France and Germany, and beer in Australia, France and Germany were early successful applications for refrigeration technology in the late 1860's to 1890's. Large-scale cold storage for fruit, especially apples, was developed in the USA and UK in the late 1890's. Cold storage for other types of fruit was developed in the early 20th century (Thevenot 1979: 407–422).

THE PROCESS OF MAKING ICE AND COLD STORAGE

The principle of refrigeration is that when a liquid evaporates to a gas or when a compressed gas is allowed to expand, the heat used is taken from the surrounding environment, thus causing cooling. Early refrigeration plants used either carbon dioxide, ammonia or sulphur dioxide as the refrigerant. Of these, ammonia was the most important commercially. In the 1930's, non-toxic refrigerants called "Freons" were developed which were thought to be safe and are still widely used today (Thevenot 1979: 39–43, 55, 253). It has recently been realised that these gases damage the ozone layer of the atmosphere, posing a serious threat to life on the planet.

In the early ice-making plants, the refrigerant gases were discharged into the atmosphere after use. In 1877, Karl von Linde developed his double-

acting horizontal ammonia compressor in order to convert the ammonia gas back into its liquid form for re-use. The compressors were soon manufactured and sold around the world (Thevenot 1979: 445). Kilometres of piping conveyed the refrigerant gases around the plants. The pipes could be immersed in brine to cool it below freezing point, so that buckets of fresh water could be frozen. The cold-storage chambers were also lined with refrigerant piping, which kept the air at a low temperature. Frozen carcasses were hung from hooks attached to rails. See, for example, the illustration of the interior of the La Plata cold storage in Argentina, where hundreds of carcasses could be moved around the chamber by this method (Critchell & Raymond 1912: 84).

DEVELOPMENT OF THE HENRY JONES ICEWORKS

Before the advent of mechanical refrigeration, ice for use in spring and summer was stored in ice-houses on Mount Wellington. These ice-houses were in use from the 1850's until the 1890's by Hobart confectioners, who used the snow and ice to make ice-cream etc. Ice was collected from the mountain in winter and stored in thick-walled stone huts, roofed with wood and turf (Thwaites 1974).

The Henry Jones iceworks was not the first manufactory of artificial ice in Hobart. There were at least two others. Degraves established an Ice Manufactory at Cascades in 1875–76 which was still in use in the 1890's (Thwaites 1974). However, this had closed down by the time Frederick Pender established the Hobart Freezing Company in the New Markets at Lower Macquarie Street in 1897. This was primarily to freeze fish for export but also produced ice for general consumption and provided cold storage for meat and dairy products (Anon. 1899: 318). The Hobart Freezing Company was burnt down in the fire which destroyed the New Markets in 1909. The site is now occupied by the City Hall.

The date at which the iceworks was established at 35 Hunter Street is not as yet known from documentary sources (Pearce 1986: 2). However, a glowing account of the Henry Jones enterprise published in 1899 makes no mention of ice-making, despite detailed descriptions of other operations of the factory (Anon. 1899: 356–359). This strongly suggests that the iceworks was established after that date. The installation of the cold-storage and ice-making equipment required structural alterations to the building, including reflooring. Richard Morrison has suggested that the addition of a new facade was a part of this reconstruction. The work must have taken place after 1899, when a streetscape photograph shows the old facade (Anon. 1899: 357), but before 1905, as a Beattie photograph taken around that date shows the new facade in place (Sprod 1977: 83). It almost certainly was done at the same time as the building across the laneway at 37 Hunter Street was constructed, as the stylistic details are identical (pl. 1). That building was the Tasmanian Refrigerating Company erected in 1903 (*Tasmanian Mail* 6 June 1903: 25); it therefore seems reasonable to postulate that the cold storage and ice-making facilities at 35 Hunter Street were established at that date, probably as part of the same operation. The technology of refrigeration was well-established by this time, having been developed both in Australia and overseas for half a century.

Meat, poultry, fruit, hops, fish, butter, eggs and other produce were kept in the cold store (Anon. 1931: 192; Jones and Co. 1926; *The Mercury* 28 January 1922: 11). Critchell & Raymond (1912: Appendix VII) list all the major meat-freezing works operating in the southern hemisphere in 1912. The Tasmanian cold-storage facility is not mentioned in their list. As the IXL cold store was almost certainly in existence by this time, its omission probably indicates that it was not primarily used for freezing meat but for chilling fruit.

The first ice-making plant used liquid ammonia as the refrigerant. The process used by Henry Jones (IXL) in Hobart in 1922 was described in *The Mercury* (28 January 1922). To make ice, cans were filled with fresh water and lowered into a tank containing 3000 gallons (11.36 m^3) of brine. Liquid ammonia was released through coils of one-inch iron piping lying in the tank and as the ammonia turned from liquid to gas, it drew heat from the surrounding brine thereby reducing its temperature to 12°F. The fresh water in the cans was then frozen solid. Refrigerant pipes also lined the cold-storage chambers to chill the air temperature and conducted the spent ammonia back to the compressors. A total of 13.5 miles of piping was used used at the ice-works, 1.3 miles (7000 ft) of which were used in the brine tank (*The Mercury* 28 January 1922: 11). In the early years of the operation the ammonia passed through the pipes as gas and was the released into the atmosphere at the end of the process.

In 1903, a 28-ton Hercules freezing plant was installed at the Tasmanian Refrigerating Company (*Tasmanian Mail* 6 June 1903: 19). By 1922, two Linde wet compressors were in use in conjunction

PLATE 1
The facade of the Old Iceworks (photo: P. Spratt).

with a condensation tower to liquefy the ammonia and thus recycle it; one is illustrated in the *Mercury* article cited above. These machines compressed the ammonia gas which was then pumped through 3.8 miles (20 000 ft) of piping in a condensation tower. Cold water, pumped from the River Derwent, was run over the pipes, cooling the ammonia to a liquid which was then recirculated. There were 22 refrigerating rooms at IXL, providing 450 000 cu. ft (12 750 m^3) of space (*The Mercury* 28 January 1922: 11), far more than the seven insulated rooms which survived in the Old Iceworks building at 35 Hunter Street. The other cold-storage rooms, the switchroom and the compressors must have been located in 37 Hunter Street and other nearby Henry Jones properties. At this time there was a 3000 gallon brine tank, the capacity of which was only enough to keep one of the Linde compressors busy. Thirty tons of ice could be made in 24 hours but the actual output was much lower. In December 1921, 104 tons of ice were made. In 1931 it was claimed that most of the ice used in southern Tasmania was made here (Anon. 1931: 192).

PREVIOUS INVESTIGATIONS

The earlier history of the site has been outlined by Pearce (1986). A building was erected on this site, on what was originally Hunter Island, some time between 1830 and 1846, a period of vigorous mercantile expansion. Its similarity to the store and residence built in 1827 at adjacent 33 Hunter Street can be seen in illustrations of the older building (Anon. 1899: 357) and suggests that the two buildings perhaps shared a similar function.

The structure of the iceworks building has been described by Consulting Chartered Engineer, Peter Spratt of England Newton Spratt & Murphy Pty Ltd, who also surveyed and drew up plans of the building whilst assessing its structural integrity (England *et al.* 1986). It was a three-storey stone building with a separate brick facade. Most of the interior was lined with timber boarding, with the gap filled with charcoal and/or wood-wool insulation. Assuming, as suggested by Spratt, that the building plans originally matched the older adjacent building at 33 Hunter Street, considerable alterations took place at the same

time as the new facade was built, including the insertion of new floor levels and the construction of a new roof.

The exterior elevations of the building were recorded using photogrammetry by the Hydro-Electric Commission under the supervision of Richard Morrison. The interior was considered by Spratt to be too dangerous to allow safe access for the photogrammetry crew, so that area was not covered in the survey. These photographs and glass negatives are stored at the Archives Office of the Tasmanian State Library. Examination of the building by Spratt during and after demolition confirmed that its southeast and northeast walls were part of the pre-1846 building, erected against the earlier adjacent structure at 33 Hunter Street. Timber plates built into the southeastern wall match those in the far wall, showing the southeast wall to be original wall construction and confirming the similarity of the buildings' plans. The northwestern wall was socketed, showing where the floor timbers had been added (P. Spratt, pers. comm.).

ARCHAEOLOGICAL EVIDENCE

One inspection was made of the ground floor of the building on 5 August by the author with A.P. Andrews, Curator of Applied Science. The purpose of this visit was to note the quantity, condition and location of any ice-making or cold-storage equipment, in order to determine what processes took place there and to provide data for an assessment of the cultural significance of any relics.

The three-storey brick and stone structure had various wooden features attached to it. There were a lift and stairway attached to the back (northeast) wall and an adjacent wooden structure which crossed Iceworks Lane at first-floor level (Fig. 1). Only the ground floor was accessible, the first and second floors, laneway structure and rear external structures being inaccessible for safety reasons. The building is not lit by electric or other lighting and there are no windows. The only natural light was that which filtered in through the open front and back doors. Consequently most of the inspection took place by torchlight. A set of record photographs of the ground-floor interiors were taken, which are held at the Tasmanian Museum and Art Gallery. Following this site visit, the building was completely closed for safety reasons, precluding any further access, although it was again inspected during demolition by Richard Morrison and Phil Andrews. Figure 1 shows a plan of the building based on that prepared by Consulting Engineer Peter Spratt. On it are marked the locations of refrigerating equipment as seen in 1986.

Ground Floor

The ground floor comprised four rooms and an entrance passage, which are numbered rooms 1 to 5 in figure 1. As noted by Peter Spratt (England *et al.* 1986: 2), every room was lined with timber boarding and the gap filled with charcoal insulation.

Room 1 was the entrance hall. There were two remaining ice-chutes in the room. One of these was still in place below the ceiling. Its purpose was to deliver ice to the street through an opening above the front door. The other chute was lying displaced on the floor. In the passage between Rooms 2 and 3 there was a large insulated door with a smaller door inset. Near the front door, the timber lining had come away from the internal wall allowing the charcoal packing to spill out on the floor (pl. 2).

Room 2 was a square room at the front of the building, with a capacity of 25 m^3. The northwest and northeast walls and the ceiling were covered with sinuous iron piping (pl. 3), which appeared to be one continuous pipe, held in place against the walls by iron bars and against the ceiling with U-shaped brackets. The purpose of the piping was to convey the low-temperature refrigerant around the cold-storage chambers. The front (southwest) wall had an insulated door through to Hunter Street. The southeast wall had a small square window through to the entrance passage (Room 1), which had an insulated window cover. Below this window there was a quantity of charcoal which had spilled out of the wall and heaped against it.

Room 3 was a narrow rectangular room with a capacity of 34 m^3. It had sinuous piping attached to the ceiling. In the north corner were some buckets made from square kerosene-style cans. These were used for making ice in the brine tank.

Room 4 was a wider rectangular room with a capacity of 48 m^3. The southwest wall had an insulated door through to the entrance passage. The northeast wall had a window opening through to Room 5. The ceiling was covered with sinuous piping.

Room 5, with a capacity of 39 m^3, occupied the whole width of the northeast side of the building. It had sinuous piping on part of the ceiling. The rest of the ceiling area was occupied by the base of a

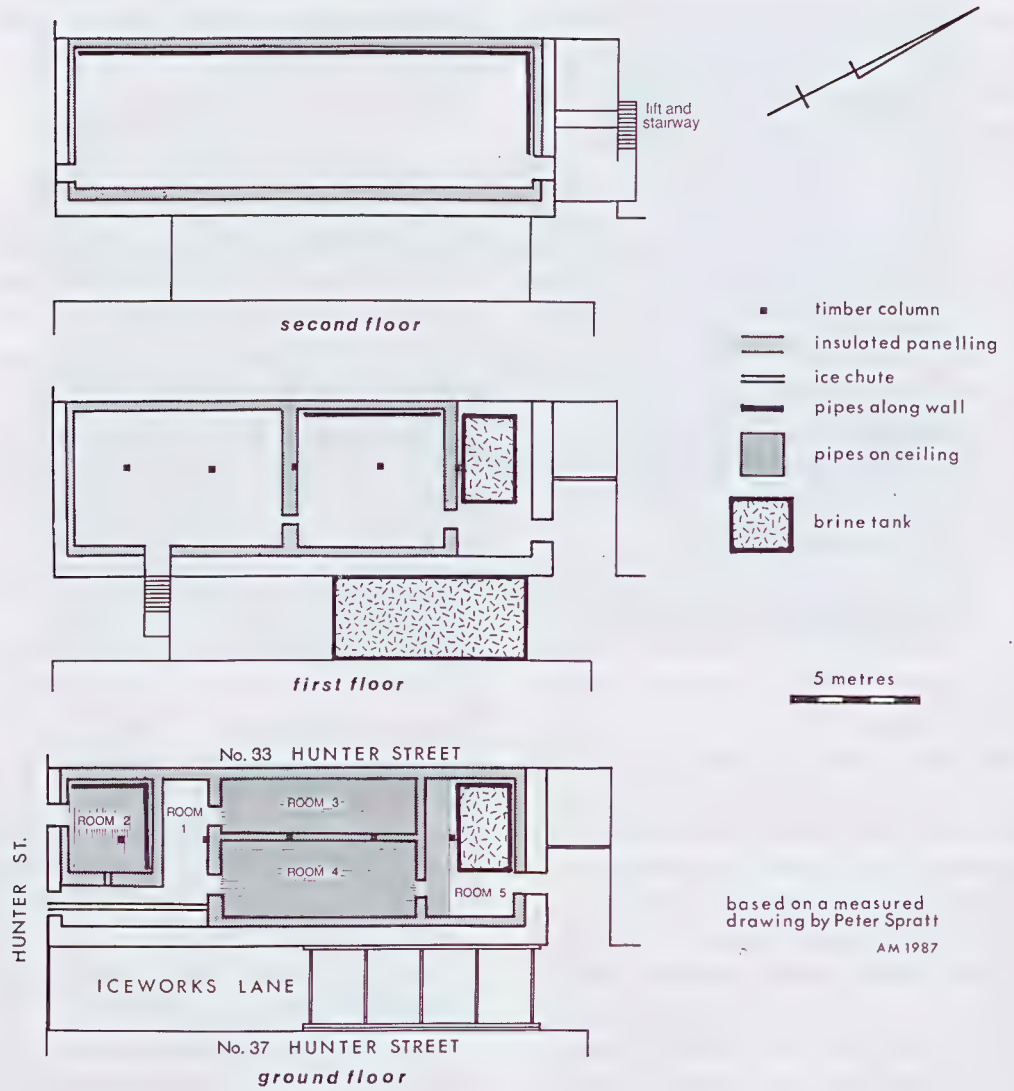

FIG. 1 — Plan of the Old Iceworks, 35 Hunter Street, Hobart, showing the location of equipment, August 1986.

PLATE 2
Charcoal insulation in Room 1.

PLATE 3
Refrigerant piping lining the walls in Room 2.

PLATE 4
Base of the brine tank visible in the ceiling of Room 5.

large iron tank which projected down from the floor above (pl. 4). This has been provisionally identified as a brine tank. Larger diameter pipes, insulated with wood-wool and some synthetic insulating material, ran the length of the building below the ceiling of Rooms 4 and 5.

First Floor

The first floor was not examined by the author. The plan of the building shows two insulated rooms, at the front and in the centre, and one smaller uninsulated room at the rear northeast end. The capacity of the two insulated rooms is 92.5 m^3 and 67 m^3. Photographs taken by Peter Spratt show some refrigerant piping in the central room and some ceiling rails and hooks in the rear uninsulated room. These rails were probably for moving frozen goods around the chambers. During demolition the brine tank, the base of which was seen in the ceiling of the room below, was noted in the rear uninsulated room. It had an approximate capacity of 6 m^3.

The Laneway Structure was functionally related to the first-floor section of the iceworks. Large pipes ran from 35 Hunter Street through to this structure. The structure itself was not examined by the author, for safety reasons. During demolition, a second iron brine tank, occupying the back-half of the Laneway Structure, was noted by Peter Spratt. The masonry walls on both sides of this tank (at 35 and 37 Hunter Street) had been shattered by freezing, necessitating the demolition of the Laneway Structure and the wall of 35 Hunter Street (P. Spratt, pers. comm.).

Second Floor

The second floor was not examined by the author. The plan shows one large insulated room occupying the entire floor, with a capacity of approximately 213 m^3. Photographs taken by Peter Spratt show refrigerant piping against at least one wall (the northeast wall) and possibly also the northwest wall. At least one wall had no piping against it.

Miscellaneous

The outside rear of the building had a lift and a stairway. These were not examined for safety reasons. The facade has four windows painted with gold lettering which read "Cold Storage for Butter, Cheese, Poultry, Eggs and Fruit", ... illegible ..., "John Paterson" and "Direct Exporter of Rabbits & Hares" (pl. 1). The roof had some items of small portable equipment including ice-buckets on it. Artefacts associated with the iceworks were also found in other parts of the Henry Jones sites. These included switches used to operate the compressor, which were mounted on composition slabs stacked in an adjacent hall to the north of the iceworks.

DISCUSSION

The available historical evidence indicates that an iceworks was established at 37 Hunter Street in 1903 and in 35 Hunter Street before 1922. The physical evidence clearly suggests that the installation of the refrigerant equipment in 35 Hunter Street necessitated major alterations to the existing building. Morrison (pers. comm.) has suggested that these alterations were most probably carried out when the brick facade was added. This probably occurred in 1903, at the same time as the dated matching facade was built at 37 Hunter Street. Therefore, the material evidence points to a date of 1903 for the installation of the refrigeration equipment at 35 Hunter Street. By this time refrigeration was a well-established and widespread technology in Australia, although its application to fruit storage was a fairly recent innovation.

The surviving iceworks at 35 Hunter Street, known as "The Old Iceworks" was in fact only a part of a much larger facility for the Henry Jones (IXL) jam factory, consisting of 22 rooms. The old iceworks building contained nine rooms altogether, seven of which were insulated and six of which had refrigerant piping lining the walls and/or ceiling. The insulated and refrigerated capacity of the building is given in table 1. The total volume of insulated space available in this building was approximately 523 m^3 and the refrigerated space 430 m^3, compared to 12 750 m^3 (450 000 cu. ft) reported earlier (*The Mercury* 28 January 1922), suggesting that most of the cold-storage facilities were located elsewhere in the complex.

Two brine tanks on the first floor and an ice-chute leading from the first floor to an outlet above the front door indicate that ice was also made on these premises. One of these tanks had been installed partly in the ceiling of the ground-floor back room and would therefore appear to be part of the original iceworks equipment. The capacity of this tank was about half of the one described in 1922. The other tank occupied half of the first-floor level laneway structure. This tank appears to have had a larger capacity than the 3000 gallon tank described in 1922. Although only one tank was mentioned, the increase in capacity suggests that this expansion of the iceworks had taken place by that time and that most, if not all, the ice-making was undertaken in this building.

The conservation status of early iceworks and ice-making equipment in Australia is poor. As far as the author has been able to ascertain, there are no iceworks in Australia which are preserved or protected or recognised in heritage listings such as the National Trust classifications and the Register of the National Estate. Also, no museum has a collection of early cold-storage equipment, although the Museum of Victoria holds a Werner compressor, made at Richmond, Victoria, which is in first-class order (Birmingham *et al.* 1979: 138).

Birmingham *et al.* also illustrate (1979: 137) an ice and fish-freezing works at Batemans Bay, New South Wales, which, at that time, still had some of its 11 km of piping, despite being used as a garage. However, there are no remains of Harrison's Melbourne works, and Mort & Nicolle's Sydney works have disappeared since 1970 (Birmingham *et al.* 1979: 137). It is thought that there are now no remains of ammonia iceworks in New South Wales (L. Newell, pers. comm.). In Victoria, remains of at least two early iceworks still survive. At Geelong there is an early refrigerating plant, although the

TABLE 1

Capacity of Insulated Rooms in 1986

Location		Capacity m^3	Refrigerated
Ground floor —	Room 2	25.8	yes
	Room 3	34.8	yes
	Room 4	48.7	yes
	Room 5	39.8	yes
	Room 1	uninsulated	no
First floor —	Room 6	92.5	no
	Room 7	67.6	yes
	Room 8	uninsulated	no
Second floor —	Room 9	213.5	yes
Total refrigerated space		430.2	
Total insulated space		522.7	

equipment is in bad condition, and at Abbotsfield the engine room, including the carbon dioxide compression equipment, still exists at the Abbotsford brewery (B. Sidebottom, pers. comm.). In Tasmania, Benders freezing works at Launceston still has its sawdust insulation, although no machinery survives (Morris-Nunn & Tassell 1983: 416).

Particular items of working equipment are more likely to survive. Birmingham *et al.* (1979: 137) mention two Ball's Giant and one Linde compressor that were still in operation in 1979. In this context, the loss, though unavoidable, of the Hobart iceworks site is a matter of regret. It represented an industrial function which was important to the development of Tasmania's fruit-processing industry and export trade from the early 20th century. The iceworks and cold storage were typical and representative of the large numbers of early 20th-century refrigeration facilities throughout Australia. Sadly, very few examples still survive.

ACKNOWLEDGEMENTS

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REFERENCES

Anon., 1899: *CYCLOPEDIA OF TASMANIA*, Vol.1. Maitland and Krone, Hobart.

Anon., 1931: *CYCLOPEDIA OF TASMANIA*. Hobart.

Birmingham, J., Jack, I. & Jeans, D., 1979: *AUSTRALIAN PIONEER TECHNOLOGY, SITES AND RELICS*. Heinemann Educational Australia, Richmond, Victoria.

Critchell, J.T. & Raymond, J., 1912: *A HISTORY OF THE FROZEN MEAT TRADE*. Constable, London.

England, E., Newton, H., Spratt, P. & Murphy, H., 1986: Henry Jones Buildings, Hunter Street. Old Freezer Building — Structural investigation. Unpubl. correspondence to Department of Construction, Tasmania.

Farrer, K.T.H., 1980: *A SETTLEMENT AMPLY SUPPLIED*. Melbourne University Press.

Jones & Co., 1926: *TASMANIA THE BEAUTIFUL GARDEN STATE OF AUSTRALIA AND IXL PRODUCTS*. H. Jones and Co., Hobart.

Linge, G.J.R., 1979: *INDUSTRIAL AWAKENING. A GEOGRAPHY OF AUSTRALIAN MANUFACTURING 1788 TO 1890*. ANU Press, Canberra.

McGowan, A., 1986: Old Iceworks, 35 Hunter Street, Hobart. A preliminary archaeological report with recommendations for acquisitions and display. Unpubl. rep., Tasmanian Museum and Art Gallery.

Morris-Nunn, M. & Tassell, C.B., 1982, 1983: *LAUNCESTON'S INDUSTRIAL HERITAGE: A SURVEY*. Australian Heritage Commission, Canberra, and Queen Victoria Museum, Launceston.

Pearce, V.F., 1986: Report on the Status of the Historical Documentation of the Old Iceworks, 35 Hunter Street. Unpubl. rep. to the Sullivans Cove Development Authority.

Sprod, D., 1977: *VICTORIAN AND EDWARDIAN HOBART FROM OLD PHOTOGRAPHS*. John Ferguson, Sydney.

Thevenot, R., 1979: *A HISTORY OF REFRIGERATION THROUGHOUT THE WORLD* (Trans. J.C. Fidler). International Institute of Refrigeration, Paris.

Thwaites, J., 1974: The Mount Wellington Ice Houses. *Tasm. Tramp* 21: 82–85.

(accepted 10 February 1989)

LATE CAMBRIAN BRACHIOPODS FROM THE DENISON RANGE, SOUTHWESTERN TASMANIA

by J. B. Jago

(with one text-figure and two plates)

JAGO, J.B., 1989 (31:x): Late Cambrian brachiopods from the Denison Range, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 37–42. ISSN 0080–4703. Department of Applied Geology, South Australian Institute of Technology, The Levels Campus, South Australia 5095.

Eight unnamed species of brachiopods and one indeterminate hyolithid species are described and figured from three stratigraphic intervals within the early Late Cambrian Singing Creek Formation, Denison Range, southwestern Tasmania.

Key Words: brachiopod, hyolithid, Cambrian, Tasmania.

INTRODUCTION

The purpose of this paper is to document the brachiopods and hyolithids from the Singing Creek Formation of the Denison Range in southwestern Tasmania. The Middle Cambrian to Lower Ordovician stratigraphy of the Denison Range area (Corbett 1975) may be summarised as follows:

Denison Group —	
Squirrel Creek Formation	600 m
Reeds Conglomerate	1560 m
Great Dome Sandstone	510 m
Singing Creek Formation	720 m
——— angular unconformity ———	
Trial Ridge Beds	500 m

The upper part of the Trial Ridge Beds contains fossils of the late Middle Cambrian *Lejopyge laevigata* Zone (Jago 1979). The Great Dome Sandstone is a shallow marine–deltaic–fluvial sequence which contains abundant trace fossils, rare inarticulate brachiopods, and a gastropod similar to *Kobayashiella* (Corbett 1975).

The Singing Creek Formation comprises 720 m of quartzwacke turbidites interbedded with fossiliferous siltstone, siliceous conglomerate and slump sheets, deposited as a submarine fan complex in a fault-controlled basin (Corbett 1972, 1973, 1975). In the Denison Range, fossils are found over three stratigraphic intervals (fig. 1). Jago (1987) described the trilobites; the brachiopods and hyolithids are described herein.

The specimens were collected by K.D. Corbett in 1967 and 1968 as bulk samples rather than on a bed-by-bed basis, because of the nature of the

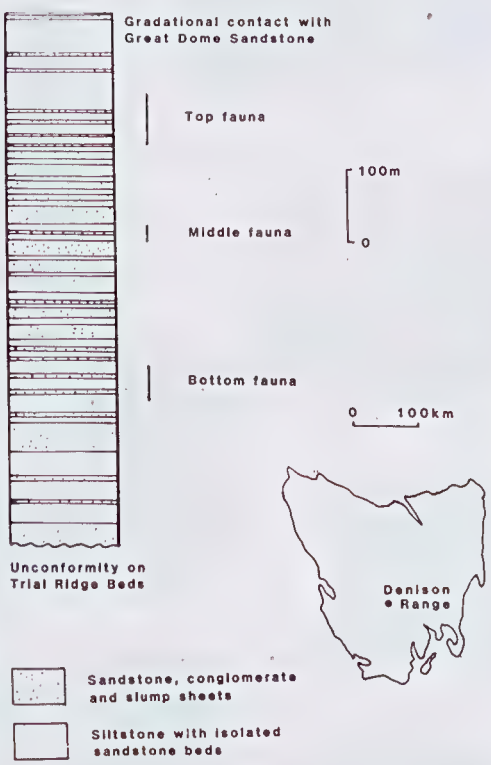


FIG. 1 — Stratigraphic position of the faunas from the Singing Creek Formation, Denison Range, southwestern Tasmania. Rock types after Corbett (1975: fig. 2). The location of Denison Range is shown.

outcrop and the difficulties of collection in this rather inaccessible area.

The lowest fauna, occurring between about 185 and 240 m above the base of the Singing Creek Formation, contains the following:

Trilobita (see Jago 1987): *Micragnostus*, *Pseudagnostus idalis denisonensis*, *Denagnostus corbetti*, *Eugonocare*, Dokimocephalidae and *Proceratopyge*.

Brachiopoda: *Lingulella* (?) sp., Acrotretidae, gen. et sp. indet. 1, and *Billingsella* sp. 1.

Only *Pseudagnostus idalis denisonensis* and *Billingsella* sp. 1 are reasonably abundant.

The middle fauna, occurring between about 410 and 430 m above the base of the Singing Creek Formation, contains the following:

Trilobita: *Denagnostus corbetti*, *Aphelaspis cantori*, *Proceratopyge gordonensis*, *P.* sp., *Pseudoyuepingia vanensis* and trilobite tracks.

Hyolithida: Hyolithid, gen. et sp. indet.

Brachiopoda: *Lingulella* (?) sp., and *Obolus* (?) sp.

In this fauna *Proceratopyge gordonensis*, *P.* sp. and *Pseudoyuepingia vanensis* are common.

By far the richest fauna is the top one which occurs between about 540 and 610 m above the base of the Singing Creek Formation. The following fossils are present:

Trilobita: *Micragnostus*, *Pseudagnostus idalis denisonensis*, *P.* sp., *Denagnostus corbetti*, *Asphelaspis cantori*, a member of the Leiostegiacea, *Proceratopyge gordonensis*, *P.* sp., and trilobite tracks.

Hyolithida: Hyolithid, gen. et sp. indet.

Brachiopoda: *Obolus* (?) sp.; Obolidae, gen. et sp. indet. 1; Obolidae, gen. et sp. indet. 2; Acrotretidae, gen. et sp. indet. 2 and *Billingsella* sp. 2.

Jago (1987) suggested that the faunas of the Singing Creek Formation are of early Late Cambrian age and fall within the range of the top three Idamean Zones, i.e. *Proceratopyge cryptica*, *Erixanium sentum* and *Stigmatoa diloma* Zones. All specimens described here are preserved as internal and external moulds in weathered siltstone or very fine sandstone. In order to prepare them for description, silicone rubber casts were prepared. These rubber casts were then photographed after being whitened with magnesium oxide. Unfortunately the brachiopods, particularly the inarticulate brachiopods, are generally poorly preserved.

The terminology used for brachiopods is after Williams & Rowell (1965a,b). All specimens are housed in the collection of the Geology Department, University of Tasmania. The catalogue numbers refer to this collection.

SYSTEMATIC DESCRIPTIONS

Phylum BRACHIOPODA Dumeril 1806
Class INARTICULATA Huxley 1896
Order LINGULIDA Waagen 1885
Family OBOLIDAE King 1846
Subfamily LINGULELLINAE Schuchert 1893
Genus *LINGULELLA* Salter 1866

Type species: *Lingula davisii* M'Coy 1851: 405.

Lingulella (?) sp. (pl. 1A-C)

Remarks: The available material comprises three internal and one external mould, all of which appear to belong in the one species. They belong in *Lingulella* or a related genus, as is indicated by their outline and ornamentation. They are too poorly preserved to warrant description.

PLATE 1

(A–C) Lingulella *(?) sp.1: (A) UT89445, internal mould of pedicle valve, × 7. (B) UT89515, internal mould of pedicle valve, × 6. (C) UT89449, external mould of pedicle valve, × 5.*

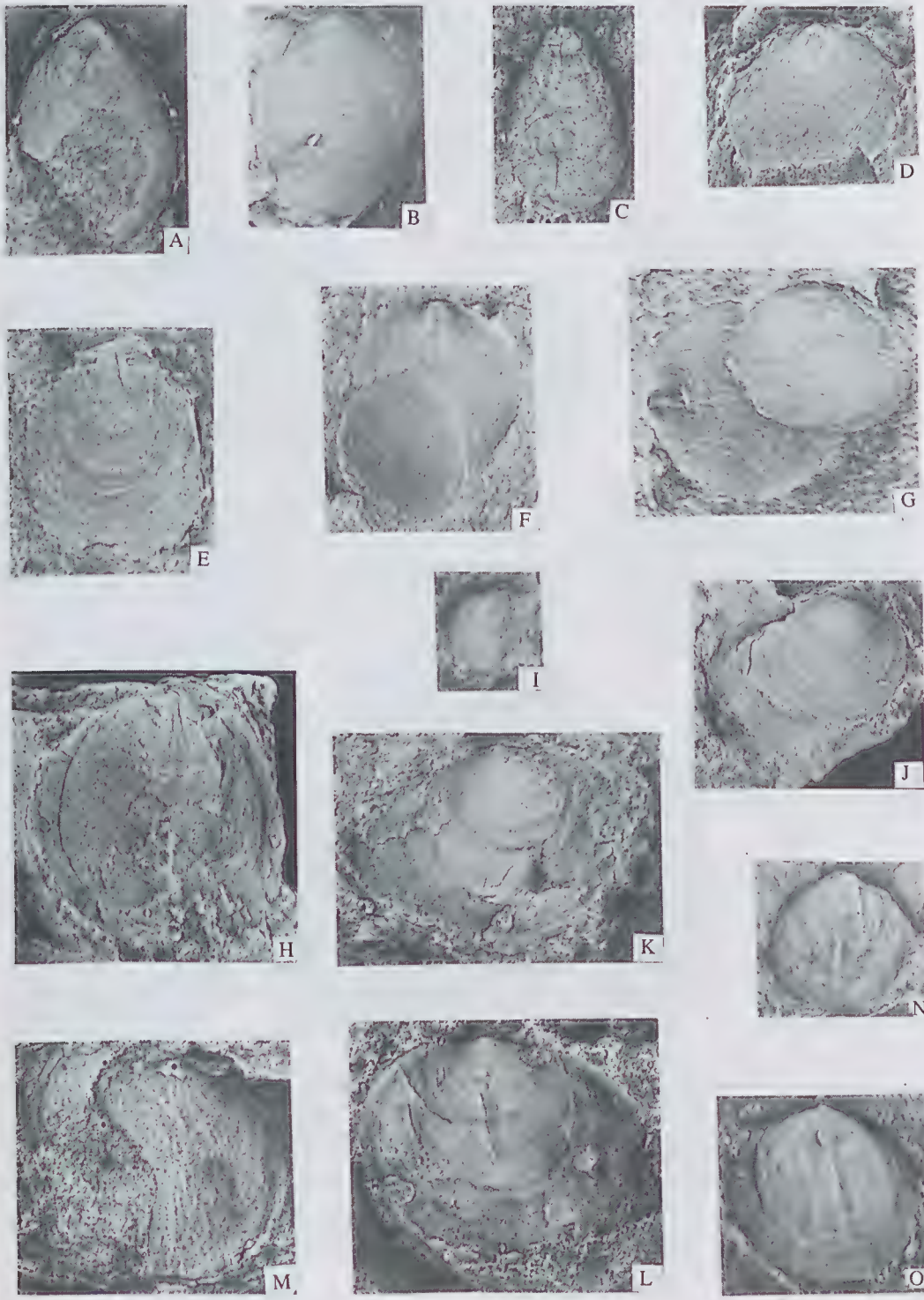
(D–H) Obolus *(?) sp.4: (D) UT89430, internal mould of brachial valve, × 6. (E) UT88427, internal mould of pedicle valve, × 4.5. (F,G) UT89431, counterparts showing both valves; (F) ×5, (G) × 6. (H) UT88433, internal mould of (?)pedicle valve, × 6.*

(I) Acrotretidae, gen. et sp. indet. 1, UT89515, internal mould of pedicle valve, × 12.

(J-L) Obolidae, gen. et sp. indet. 1: (J) UT88432, internal mould, × 3.5; (K) UT88423, internal mould, × 6. (L) UT88435, internal mould, × 5.5.

(M) Obolidae, gen. et sp. indet. 2. UT88429, internal mould, × 3.5.

(N,O) Acrotretidae, gen. et sp. indet. 2: (N) UT88431, external mould of brachial valve, × 6. (O) UT88410, internal mould of brachial valve, × 9.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Subfamily OBOLINAE King 1846
Genus *OBOLUS* Eichwald 1829

Type species: *Obolus apollinis* Eichwald 1829: 274 (pl. 4, figs 5A-B).

Obolus (?) sp. (pl. 1D-H)

Material: Three pedicle and two brachial valves preserved as either internal or external moulds.
Remarks: If it is assumed that the two valves which occur together on specimen UT89431 (pl. 1F,G) originally belonged to the same individual, then the pedicle valve is slightly larger than the brachial valve. Both valves are gently convex and have a circular to oval outline; both show fine concentric growth lamellae. The general appearance of the available specimens suggests that they belong in *Obulus*, to which genus they are tentatively assigned.

Obolidae, gen. et sp. indet. no.1 (pl. 1J-L)

Remarks: Internal moulds of three valves of a probable member of the Obolidae are figured. The details are such that it can not be determined whether they are brachial or pedicle valves.

Obolidae, gen. et sp. indet. no.2 (pl. 1M)

Remarks: One partially preserved valve exhibits closely spaced growth lamellae. There are minute spines on the surface of the valve, particularly in the posterior region. Discontinuous vascular markings are visible, particularly in the anterior part of the valve.

Order ACROTRETIDA Kuhn 1949
Suborder ACROTRETIDINA Kuhn 1949
Superfamily ACROTRETACEA Schuchert 1893
Family ACROTRETIDAE Schuchert 1893

Acrotretid, gen. et sp. indet.1 (pl. 1I)

Remarks: One poorly preserved small conical pedicle valve of an acrotretid is present. It is too poorly preserved to allow generic identification.

Acrotretid, gen. et sp. indet. no.2 (pl. 1N,O)

Material: Four poorly preserved brachial valves are available.
Remarks: These valves which have an almost semicircular outline show faintly developed growth lamellae. Their outline is similar to that of *Quadrisonia minor* of Rowell & Henderson (1978) from the Upper Cambrian of North America, but until better preserved material is available this material must be left in open nomenclature.

Class ARTICULATA Huxley 1869
Order ORTHIDA Schuchert and Cooper 1932
Suborder ORTHIDINA Schuchert and Cooper 1932
Superfamily BILLINGSELLACEA Schuchert 1893
Family BILLINGSELLIDAE Schuchert 1893
Genus *BILLINGSELLA* Hall and Clarke 1893

Type species: *Orthis pepina* Hall 1863: 134, pl. 6, figs 23–27.
Comment: As noted by Mackinnon in Shergold *et al.* (1976) *Billingsella* is a cosmopolitan genus of Middle Cambrian to Early Ordovician age. Although it has been recorded from Late Cambrian sequences in Tasmania by various authors (e.g. Banks 1962, Corbett 1975, Jago 1979), the specimens dealt with below are the first to be described and figured from Tasmania.

Billingsella sp.1 (pl. 2A-J)

Material: All specimens are disarticulated. Six brachial and twelve pedicle valves are available.
Description: Gently convex pedicle valve with subtrapeziform outline, widest at hinge line; apsacline ventral interarea about four times as wide as long; posterolateral margins of ventral interarea slightly concave; gently convex pseudodeltidium covers apical half of delthyrium; cardinal extremities angular, acute to right-angled; low median fold; slightly concave posterolateral slopes; external ornamentation parvicostellate with costellae most prominent on fold margins; variably developed concentric growth lines; details of teeth and musculature not clear on available material.

Almost flat, subrectangular brachial valve, widest at hinge line; cardinal extremities almost right-angled; shallow median sulcus; dorsal interarea details not visible on available material; external ornamentation parvicostellate with costellae most prominent in, and on the margins of the sulcus; variably developed concentric growth lines; in brachial valve interior are widely divergent socket ridges; notothyrial platform bears narrow ridge-like cardinal process.

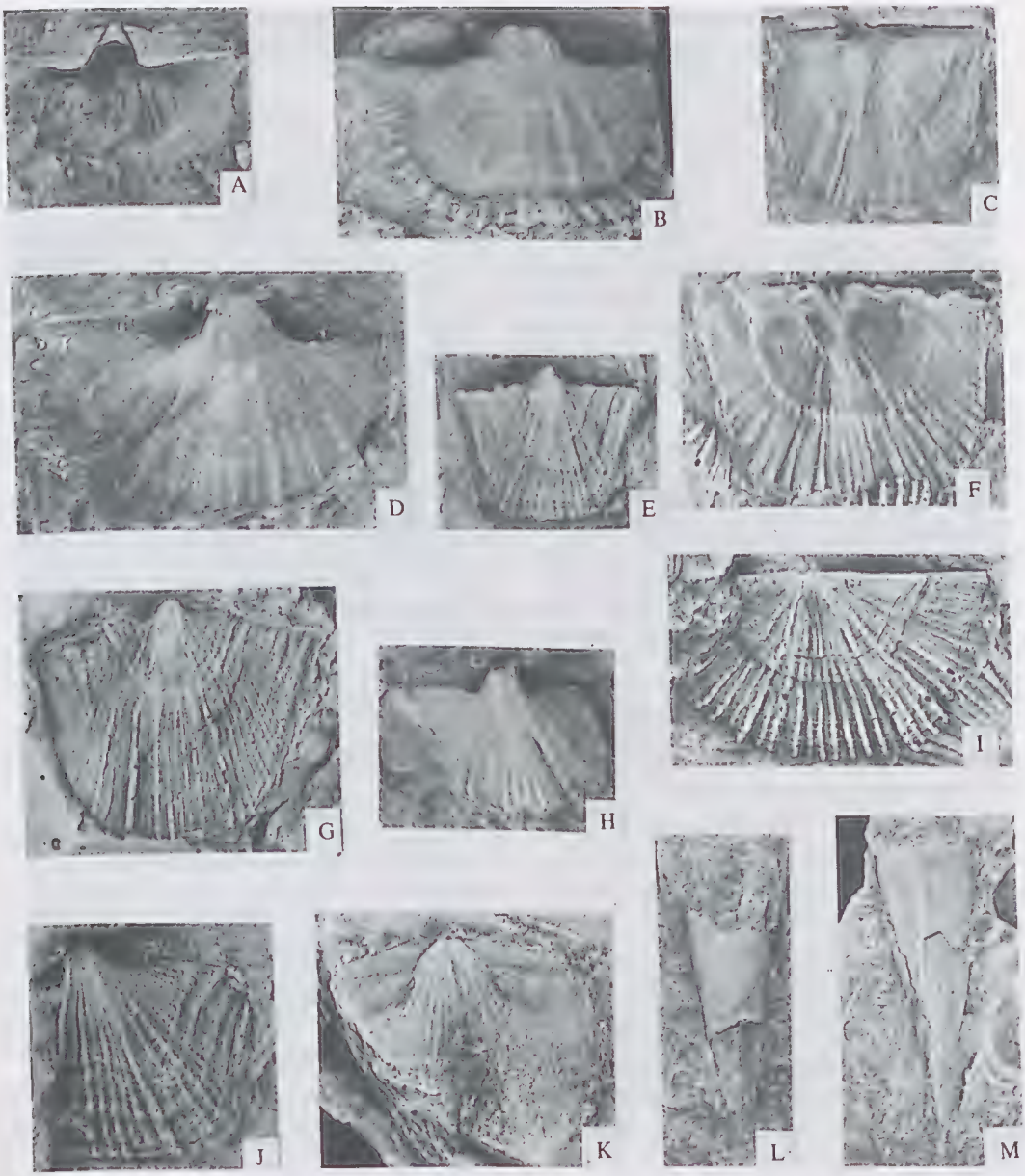

PLATE 2

(A-J) Billingsella *sp.1: (A) UT89514, internal mould of pedicle valve, × 4. (B) UT89515, internal mould of pedicle valve, × 5. (C) UT89514, internal mould of brachial valve, × 6. (D) UT89513, internal mould of pedicle valve, × 5. (E) UT89514, external mould of pedicle valve, × 3. (F) UT89516, internal mould of brachial valve, × 2. (G) UT89514, external mould of pedicle valve, × 3. (H) UT89515, internal mould of pedicle valve, × 4. (I) UT89516, external mould of brachial valve, × 2. (J) UT89515, external mould of brachial valve, × 6.*

(K) Billingsella *sp.2, UT88508, internal mould of pedicle valve, × 3.*

(L-M) Hyolithid, gen. et sp. indet.: (L) UT88390, internal mould, dorsal view, × 3. (M) UT88393, internal mould, ventral view, × 4.

Discussion: As noted by Mackinnon in Shergold *et al.* (1976) there is little published data on southern hemisphere species of *Billingsella*. *Billingsella* sp.1 (described above) differs from both *Billingsella* sp. indet. (described by Mackinnon in Shergold *et al.* (1976) from northern Victoria Land, Antarctica) and *Billingsella* sp. (described by Percival in Powell *et al.* (1982) from western New South Wales) in having a lower ventral interarea. The external ornamentation on both valves of the Tasmanian specimens is stronger than those on either the New South Wales or Antarctic species noted above. No species of *Billingsella* other than those mentioned above have been described from Australia or Antarctica; all three are of Idamean age.

Billingsella sp.2 (plate 2K)

Remarks: Several generally poorly preserved disarticulated valves are available. The only reasonably well preserved specimen, an internal mould of a pedicle valve, is figured. This pedicle valve differs from those described as *Billingsella* sp.1 in that it is widest somewhat to the anterior of the hinge line, whereas *Billingsella* sp.1 is widest at the hinge line. This, plus the fact that it comes from a higher stratigraphic horizon than *Billingsella* sp.1, suggests that it belongs in a different species of *Billingsella*.

Phylum MOLLUSCA
Class HYOLITHA Marek 1963
Order HYOLITHIDA Matthew 1899
Hyolithid, gen. et sp. indet. (pl. 2L,M)

Remarks: Five poorly preserved hyolithid specimens are available. The dorsal side is gently convex; the ventral side bears a prominent longitudinal rib, the divergence angle is 15–20°. The available material does not allow assignment of the specimens to a particular genus or species.

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REFERENCES

Banks, M.R., 1962: The Cambrian System. *In* Spry, A.H. & Banks, M.R. (Eds): *THE GEOLOGY OF TASMANIA. J. Geol. Soc. Aust.* 9: 127–145.

Corbett, K.D., 1972: Features of thick-bedded sandstones in a proximal flysch sequence, Upper Cambrian, south-west Tasmania. *Sedimentology* 19: 99–114.

Corbett, K.D., 1973: Open-cast slump sheets and their relationship to sandstone beds in an Upper Cambrian flysch sequence, Tasmania. *J. Sedim. Petrol.* 43: 147–159.

Corbett, K.D., 1975: The Late Cambrian to Early Ordovician sequence on the Denison Range, south-west Tasmania. *Pap. Proc. R. Soc. Tasm.* 109: 111–120.

Eichwald, E., 1829: Zoologia specialis, quam expositis animalibas tum vivis, tum fossilibus potissium Rossiae in universum et Poloniae in specie etc. Vol.1, 314 pp., 5 pls (Vilnae).

Hall, J., 1863: Preliminary notice of the fauna of the Potsdam Sandstone, with remarks on the previously known species of fossils and decriptions of some new ones from the sandstone of the upper Mississippi valley. *16th Ann. Rep. N.Y. Cab. Nat. Hist.*, App.D, Contributions to Paleontology: 119–184, pls Va–XI.

Jago, J.B., 1979: Tasmanian Cambrian biostratigraphy – a preliminary report. *J. Geol. Soc. Aust.* 26: 223–230.

Jago, J.B., 1987: Idamean (Late Cambrian) trilobites from the Denison Range, south-west Tasmania. *Palaeontology* 30: 207–231.

M'Coy, F., 1851: On some new Cambro-Silurian fossils. *Ann. Mag. Nat. Hist.* 20: 387–409.

Powell, C.M., Neef, G., Crane, D., Jell, P.A. & Percival, I.G., 1982: Significance of Late Cambrian (Idamean) fossils in the Cupala Creek Formation, northwestern New South Wales. *Proc. Linn. Soc. N.S.W.* 106: 127–150, figs 1–12.

Rowell, A.J. & Henderson, R.A., 1978: New genera of acrotretids from the Cambrian of Australia and the United States. *Univ. Kansas, Paleont. Contrib., Paper* 93: 1–12, pls 1–2.

Shergold, J.H., Cooper, R.A., MacKinnon, D.I. & Yochelson, E.L., 1976: Late Cambrian Brachiopoda, Mollusca, and Trilobita from northern Victoria Land, Antarctica. *Palaeontology* 19: 247–291, pls 38–42.

Williams, A. & Rowell, A.J., 1965a: Morphology. *In* Moore R.C. (Ed.): *TREATISE ON INVERTEBRATE PALEONTOLOGY*, Part H: H57–H138, figs 59–138. Geological Society of America & University of Kansas Press.

Williams, A. & Rowell, A.J., 1965b: Morphological terms applied to brachiopods. *In* Moore R.C. (Ed.): *TREATISE ON INVERTEBRATE PALEONTOLOGY*, Part H: H139–H155. Geological Society of America & University of Kansas Press.

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THE WELD RIVER GROUP: A MAJOR UPPER PRECAMBRIAN DOLOMITE SEQUENCE IN SOUTHERN TASMANIA

by C. R. Calver

(with two text-figures and two plates)

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The Weld River Group is a folded Precambrian sequence (several kilometres thick and predominantly of dolomite) that crops out in the northern Jubilee region, southern Tasmania. It overlies older predominantly siliciclastic sequences with paraconformity or angular unconformity that does not correspond to any major (cleavage-forming) tectonometamorphic event in the older successions. The group consists of a basal, relatively thin, siliciclastic unit (the Annakananda Formation), locally overlain by an impersistent pebbly mudstone (the Lake Timk Formation), followed by massive, fine-grained dolomite (the Gomorrah Dolomite), then bedded dolomite largely consisting of catagraphic, oolitic grainstone (the Devils Eye Dolomite), and then a second massive dolomite unit (the Styx Dolomite). In faulted contact with these units is a probably younger sequence of massive dolomite intercalated with dolomite-derived mixtite, mudstone and sandstone (the Cotcase Creek Formation). The older Precambrian siliciclastic sequences and the Weld River Group are unconformably overlain by a lithicwacke and conglomerate succession, probably of Middle or Upper Cambrian age. The stratigraphic setting of the group, and some lithologic features, suggest correlation with upper Precambrian dolomitic sequences in northwestern Tasmania (e.g. Black River Dolomite, Success Creek Group) implying that the Penguin Orogeny may be absent or only weakly manifested in the Jubilee region.
Key Words: Precambrian, Tasmania, dolomite, tillite.

INTRODUCTION

Inaccessibility, thick vegetation and the apparent lack of economic mineral deposits have long discouraged any significant geological interest in the catchments of the upper Weld and upper Styx Rivers. Lewis (1924) provided an exploratory account and a precursory geological map. Spry (1962), in a synthesis of the Precambrian of Tasmania, included the area in a larger region of relatively unmetamorphosed Precambrian rocks, later called the Jubilee Block (Corbett 1970) or the Jubilee region (Turner 1989a). Only recently were large tracts of Precambrian dolomite recorded in the upper Weld valley (Hall 1967). Geological mapping of the Pedder 1:50 000 Quadrangle (Turner *et al.* 1985) first established the essential unity of the dolomite sequence, its structure, internal stratigraphy and relationships with other sequences. A brief outline of this work was given by Calver (1989).

This paper is a more detailed description of the dolomite sequence, incorporating new information from mapping on the Styx Quadrangle. New stratigraphic names are proposed and matters of broader interest are briefly dealt with: e.g. correlation with sequences elsewhere in Tasmania; the nature and timing of major tectonic phases; and the origin of the mixtites and related rocks that occur in younger parts of the succession. Some aspects of this work, in particular dolomite petrography and Pedder Quadrangle geology, will be treated in more detail in Calver *et al.* (in prep.).

GEOLOGICAL SETTING

The Weld River Group is the youngest of at least three distinct Precambrian successions that comprise the northern part of the Jubilee region (fig. 1). All the Precambrian rocks are thick, cratonic, shallow-water sedimentary sequences (orthoquartzites, pelites, dolomites) in which regional metamorphism is slight (sub-greenschist facies) to negligible. First-order folds, with wavelengths of a few kilometres, face northwest, plunge steeply northwest and are upright or overturned to the northeast. The folds are thoroughly dismembered by major faults.

The rocks are multiply deformed but the intensity of deformation and metamorphism decreases in a

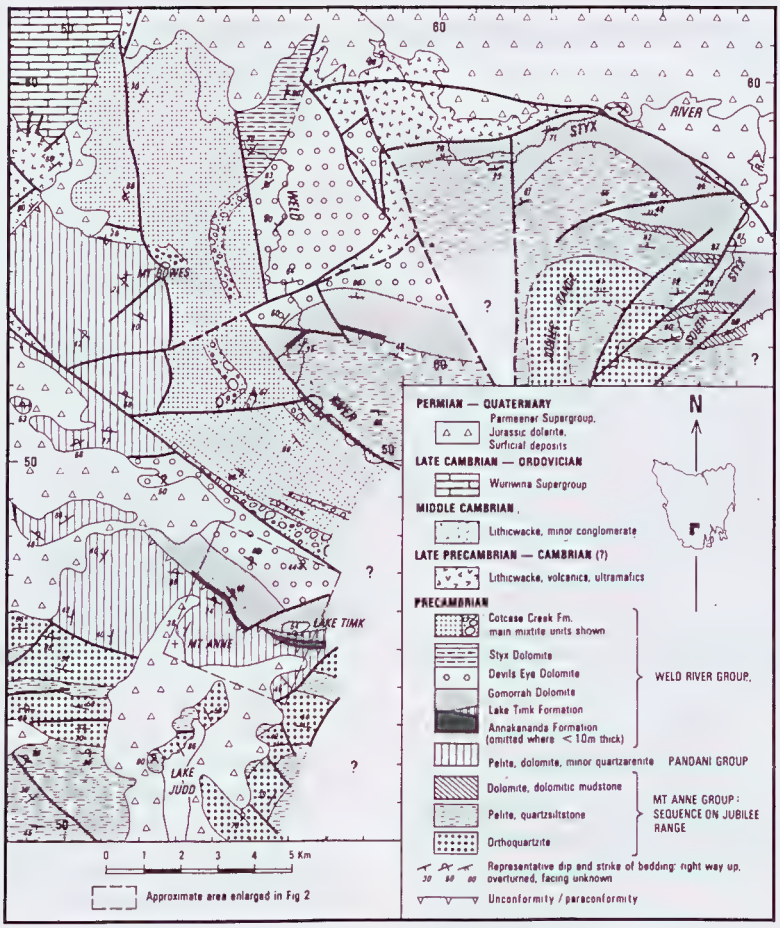

FIG. 1 — Geological map of upper Weld Valley and environs. That part of map west of 59 km E gridline is adapted from Turner et al. *(1985).*

general northeasterly direction. This is manifested chiefly by a gradual change in pelite character, from fine-grained phyllite south of Mt Anne, through slate around Sandfly Creek (DN500500), to weakly cleaved mudstone around Mt Bowes and east of the Weld River.

All these sequences, including the Weld River Group, are presumed late Precambrian, because of the total absence of fossils other than simple algal remains (stromatolites, catagraphs) and because their rock types and tectonomorphic grade are consistent with known upper Precambrian rocks of the Tyennan and Rocky Cape regions (Turner 1988). They are unconformably overlain to the north by a Middle or Upper Cambrian lithicwacke-conglomerate sequence, and faulted against a similar lithicwacke-mafic volcanics sequence of unknown age. All these rocks are unconformably overlain by upper Cambrian to Devonian rocks of the Wurawina Supergroup and by the flat-lying Permo-Carboniferous Lower Parmeener Supergroup.

STRATIGRAPHY

Older Precambrian Sequences

The base of the Weld River Group is regionally transgressive. East of the Weld River it paraconformably overlies an orthoquartzite-quartz siltstone-mudstone sequence (here informally called the "Jubilee Range sequence"), while in a separate area of outcrop north of Mt Anne, it overlies, with angular unconformity, a dolomite and mudstone sequence (the Pandani Group — Calver *et al.*, in prep.). The relationship between the Jubilee Range sequence and the Pandani Group is uncertain. The former is lithologically very similar to the Mt Anne Group (Calver *et al.*, in prep.), which crops out extensively south of the Pandani Group and may be older, as it occupies a southerly position in a predominantly north-facing structural regime.

A thick (c. 1 km) unit of greenish-grey mudstone monotonously interlaminated with quartz siltstone is generally the topmost unit of the Jubilee Range sequence. Orthoquartzite occurs lower in the sequence and forms the high strike ridges of the Jubilee Range. At the South Styx River, however, the mudstone-quartz siltstone unit grades up into an unusual unit of stromatolitic and oolitic dolomite and dolomitic mudstone, about 100 m thick, which is then overlain by the Weld River Group. Although showing greater compositional affinity with this group than with the Jubilee Range sequence, the unit is clearly part of the latter as it is gradational with, and to a small extent interbedded with the greenish-grey mudstone-siltstone unit and is overlain by a conglomerate bed correlated with the basal Annakananda Formation of the Weld River Group. The localised distribution of this unit suggests gentle overstep by the Weld River Group over the Jubilee Range sequence, even though at known localities the two sequences show no discernible angular unconformity.

The unconformity on the northeastern ridge of Mt Anne, by contrast, exhibits 20–30° of angular discordance. The Pandani Group there consists predominantly of dark grey, fine-grained slightly impure dolomite and limy dolomite interbedded with slate and phyllite.

Weld River Group

The Weld River Group is defined as the sequence (predominantly of dolomite) composed of the formations defined below, occupying most of the catchment of the upper Weld River and extending east into the Styx River valley (fig. 1). Lithologically, it is marked by a great predominance of fine-grained, pale-grey dolomite that appears relatively pure except for local secondary silicification. Total apparent thickness of the Group is of the order of 5 km, but known faulting, and more especially the undoubted presence of undetected faulting in this generally poorly exposed area, make estimates of stratigraphic thickness fraught with uncertainty. The sequence is thought to be wholly Late Precambrian in age (for reasons outlined above).

The Weld River Group is regionally folded but the thick dolomite units have behaved competently and appear unstrained at the scale of outcrop or thin-section. The volumetrically minor clastic units are, by contrast, usually cleaved and in a few places display outcrop-scale folding.

Difficulty of access, inadequate exposure and the great thicknesses of the constituent formations have precluded measurement of type sections: definition is by type area, and conformity and continuity of the sequence are inferred from constancy of bedding attitude and facing in type areas.

Karst topography is developed over much of the area occupied by the Weld River Group. Scattered surficial boulders of crystalline and chalcedonic quartz, often with much vuggy porosity, are very common, particularly in the Styx River catchment. These may be remnants of an ancient (Tertiary?) silcrete.

Annakananda Formation

The Annakananda Formation is defined as the formation of conglomerate and lithic sandstone, approximately 30 m thick, which overlies the Pandani Group with angular unconformity on the northeastern ridge of Mt Anne (DN543463) and is conformably overlain by the Gomorrah Dolomite. The formation is named after the major cave system that leads from the bottom of the large sinkhole at this locality. These karst features are developed in the basal part of the Gomorrah Dolomite. The surface of unconformity and adjacent bedding over a wide area are overturned and dip steeply southwest (figs 1, 2). At the type locality, all but the lowermost 1.5 m of the unit are well exposed in the precipitous southern wall of the sinkhole. Here the Annakananda Formation consists of (at the base) several metres of thin-bedded, yellowish brown, dolomitic lithic sandstone (in places cross-bedded and ripple-marked), followed by roughly 10 m of massive

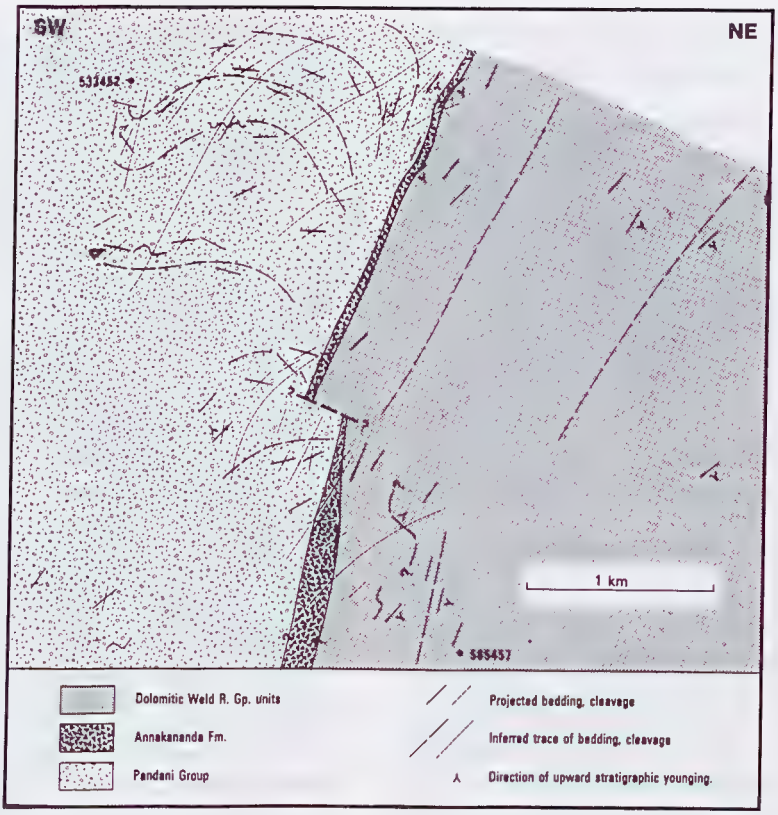

Fig. 2 — Structural profile, northeastern ridge of Mt Anne. Projection plane: view to 294°, elevation 40°.

conglomerate, then roughly 10 m of thick-bedded, fine-grained, brown dolomitic sandstone which grades up conformably into the massive grey dolomite of the succeeding Gomorrah Dolomite. The conglomerate is predominantly reddish in colour, closed-framework, and of pebble to cobble grade. It is mostly or entirely composed of clasts derived from the underlying Pandani Group: dolomite, dolomitic mudstone, orthoquartzite, phyllite and chert.

Along strike to east and west of the type locality, conglomerate is the predominant rock type; the formation thickens to approximately 100 m south of Lake Timk. In a separate area of outcrop east of the Weld River and north of the Jubilee Range, the Annakananda Formation correlate rests paraconformably upon the Jubilee Range sequence. In the Weld River (DN563533), the formation consists of a basal 300 mm thick bed of pebble-conglomerate, with clasts derived from underlying rock types (quartz siltstone and mudstone), overlain by about 10 m of red mudstone, with minor thin, planar laminae of lithic sandstone. Identical red mudstone separates the Jubilee Range sequence from a correlate of the Gomorrah Dolomite on the Styx River at DN603580. In the South Styx River area, where a dolomitic unit locally occurs at the top of the Jubilee Range sequence (see above), the Annakananda Formation correlate consists of a few metres of sandy dolomitic conglomerate and breccia.

Lake Timk Formation

The Lake Timk Formation is defined as the unit of pebbly dolomitic mudstone and siltstone that crops out immediately south of Lake Timk, in a position stratigraphically between, and structurally

conformable with the Annakananda Formation and the Gomorrah Dolomite. The formation (up to 300 m thick) appears to thin westward and disappears west of Lake Timk, suggesting stratigraphic impersistence, but, as neither base nor top is exposed, fault emplacement cannot be ruled out. Bedding is overturned and dips south. The formation consists of black to grey-green mudstone, with thin planar laminae of lighter-coloured quartz-rich siltstone and sparse floating granules and pebbles of dolomite and quartzite in places.

Gomorrah Dolomite

The Gomorrah Dolomite is defined as the unit of massive, fine-grained, pale-grey dolomite, about 800 m thick, conformably overlying the Annakananda Formation in the sinkhole exposure described above and overlain conformably by the Devils Eye Dolomite at around DN550468 on the northeastern ridge of Mt Anne. The top was not observed but may be defined as the base of the first occurrence of predominantly bedded dolomite that is characteristic of the Devils Eye Dolomite. The formation is named after the large eastern spur (DN555465) of Mt Anne's northeastern ridge.

Most outcrops are massive and uniform, typically with a network of etched, fine, random fractures or joints and, in places, veins of dolomite or quartz. In some outcrops, primary lamination is preserved as colour-banding or as slight textural variations, manifested as a relief-pattern on weathered outcrop surfaces. Thin sections show an anhedral, recrystallised fabric with lamination, where present, defined by variations in grainsize (0.02–0.2 mm). Indistinct, slightly opaque clots which are present may be ghosts of original peloids. Rare beds of grainstone (see below) are present. A few outcrops contain up to 30% well-rounded quartz sand grains. There are rare siliciclastic intervals, notably an impersistent unit of interbedded mudstone, lithic sandstone and minor chert locally cropping out just west of Lake Timk.

A lithostratigraphic correlate of the Gomorrah Dolomite occurs in the Weld Valley and extends east, offset by several faults, to the South Styx River.

Devils Eye Dolomite

The Devils Eye Dolomite is defined as the unit of predominantly bedded dolomite, conformably overlying the Gomorrah Dolomite (as described above) at DN550468 on the northeastern ridge of Mt Anne. This section is terminated by a major fault 1300 m above the base of the Devils Eye Dolomite, so a composite type area is necessary and the top of the formation is defined where its lithological correlate in the Weld River area is overlain by the Styx Dolomite at DN554578. Here also the formation is faulted; the thickest apparently unfaulted section is about 2.5 km thick. However, poor exposure and the possibility of undetected faulting render this uncertain as an estimate of stratigraphic thickness. The name of the formation is derived from a large cave at DN556472.

Like the underlying Gomorrah Dolomite, this formation is composed almost entirely of clean, pale–grey dolomite but is distinguished by the presence of numerous beds in which arenaceous or rudaceous grainstone textures are preserved. In some outcrops, grainstone is pervasive, but usually there is considerable interlayered fine-grained, uniform dolomite. Bedding in weathered outcrops is usually enhanced by selective partial silicification of the grainstone layers and is thus readily discernible in most place, unlike the situation in the predominantly massive dolomite of the rest of the Weld River Group.

The grainstone beds are usually gently lenticular and are frequently cross-bedded, with sets 0.05–0.1 m, rarely 0.2 m in thickness. Herringbone cross-bedding is common. Locally developed at the bases of some beds, and filling shallow scours, are thin lenses of flat-pebble breccia.

In thin sections, the primary constituents of the grainstones are generally well-preserved and can be identified as catagraphs, ooids, peloids and intraclasts (pl. 1). Catagraphs (spheroidal to irregular grains with micritic rims, possibly of microbial origin: Hofmann 1987) are the most abundant component volumetrically (pl. 1A). Ooids are all concentrically layered, lack radial structure and are often compound (pl. 1B). Pure oolite rock is rare. Flat-pebble breccias often exhibit a geopetal fabric (shelter porosity) (pl. 1C).

No siliciclastic rocks are known from this formation. A dolomite pebble-cobble conglomerate, almost wholly of intrabasinal provenance but for rare orthoquartzite clasts, crops out on the fault-line scarp (DN560480) that terminates the northeastern ridge section.

Styx Dolomite

The Styx Dolomite is defined as the unit of massive, pale-grey, fine-grained dolomite that

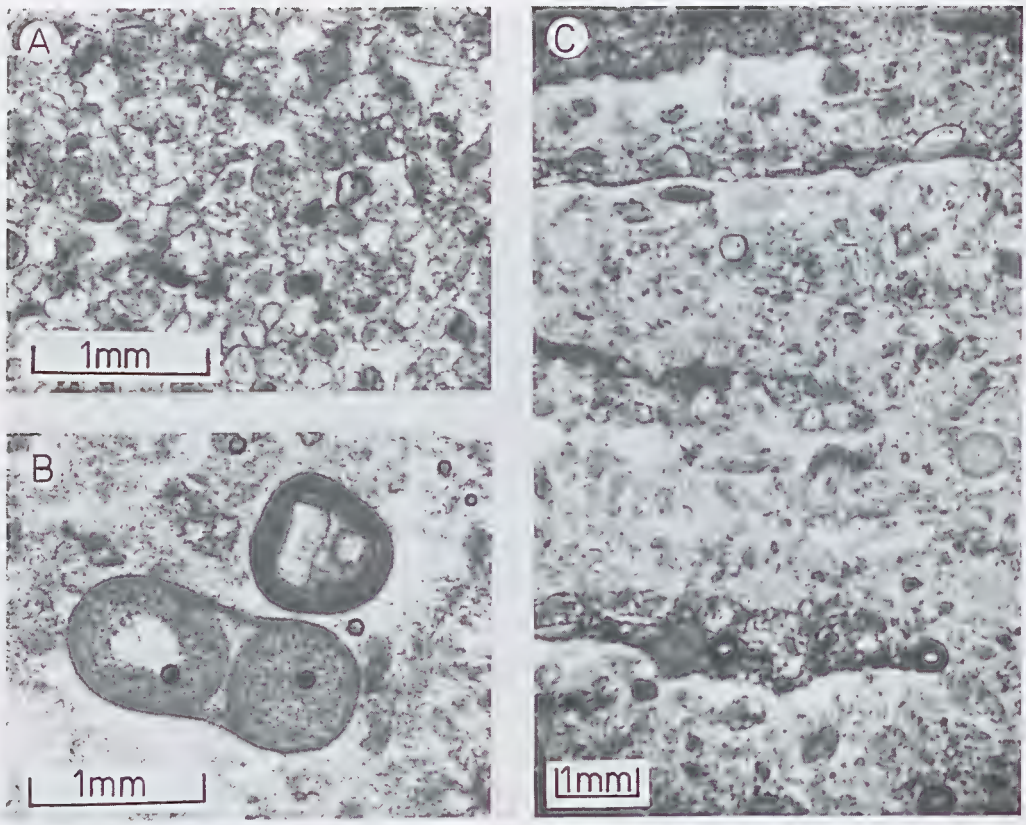

PLATE 1

Photomicrographs, with plane-polarised light, of grainstone types from the Devils Eye Dolomite: (A) catagraphic grainstone, (B) oolitic grainstone, (C) intraclastic grainstone. Light-coloured areas immediately beneath large platy intraclasts in (C) are cement-filled voids (shelter porosity).

overlies, probably conformably, the Devils Eye Dolomite in the Weld River at DN554578; the base is taken as the top of the last grainstone bed. The formation is well-exposed upstream as far as DN548581, this section representing an apparent thickness of about 500 m, but is poorly known elsewhere; the top of the unit is not exposed. To the west, the Styx Dolomite is faulted against the Cotcase Creek Formation; it may be partly equivalent to this formation but appears to lack the characteristic mixtite units.

The predominant rock type is that typical of massive dolomite elsewhere in the Weld River Group (Gomorrah Dolomite, Cotcase Creek Formation). Most outcrops in the lower 300 m of section in the Weld River contain several per cent rounded quartz sand grains, which tend to be scattered through the rock without being concentrated into beds or laminae; oolitic coatings were observed on some quartz grains. Near the top of the river section there are two small outcrops of red mudstone with thin planar sandstone laminae.

Cotcase Creek Formation

The Cotcase Creek Formation is defined as the unit, predominantly of massive, fine-grained, pale-grey dolomite, with intervals of mixtite, sandstone, mudstone and chert, that occupies the western half of the catchment of the upper Weld River (fig. 1). It is named after a western tributary of the Weld.

The formation is poorly known due to difficulty of access, poor outcrop and the paucity of facing evidence; no top or base to the sequence is known.

It is faulted against other units of the Weld River Group. Although there is no proven stratigraphic continuity with the other units, this formation is included in the Weld River Group on the basis of proximity and similar gross character to the previously described formations. Since the other formations constitute a well-established sequence overlying dissimilar, older Precambrian rocks, the Cotcase Creek Formation is taken to be younger.

Sparse facing evidence suggests the whole outcrop belt may be the steeply west-dipping limb of a fault-modified, first-order, northwest-plunging anticline, with a northern limb represented by the north-dipping rocks east of the Weld River (fig. 1). Rare reversals of facing imply tight folding and greater structural complexity, but no closures were mapped in the field. A conservative thickness estimate of, say, 2 km necessitates some structural repetition to account for the full width (3–4 km) of the outcrop belt.

Dolomite in the Cotcase Creek Formation is lithologically identical to the other largely massive, fine-grained units (Gomorrah and Styx Formations). There are rare, isolated grainstone beds similar to those of the Devils Eye Dolomite.

Several mixtite units have been mapped, ranging from a few metres to perhaps 400 m thick. In some instances they appear to be laterally impersistent, although poor outcrop and the strong possibility of undetected faulting render this an uncertain observation. Typically the unit is a wholly massive rock composed of 5–30% angular to sub-rounded clasts, pebble to cobble size (rarely, to boulder size), in a black, carbonaceous, dolomitic sandy mudstone matrix (pl. 2A). In places there is a weak cleavage and weak tectonic alignment of clasts. The clasts are predominantly white to pale-grey dolomite identical to the enclosing sequence, with minor mudstone, orthoquartzite, quartz siltstone, chert and a single altered basaltic fragment. Contacts of mixtite units with the enclosing dolomite sequence are generally abrupt or marked by an intervening unit of laminated black mudstone, black quartzwacke or dolomite conglomerate. Dolomite clasts in the conglomerates and mixtites are all recognisable Weld River Group types, except for an unusual variety of oolite consisting of very small (0.07–0.25 mm) radial-fibrous ooids.

There is some variation (within and between mixtite units) in composition, maximum clast size and clast–matrix proportion. For example, a unit about 200 m thick, just south of the Weld River (DN562513), has a few metres of black dolomitic quartzwacke at the base, followed by boulder mixtite with abundant (30%) clasts, then sparse (5%) mixtite making up the bulk of the unit, with more clast-rich rock reappearing near the top contact. In some other localities, no clasts larger than granules are present.

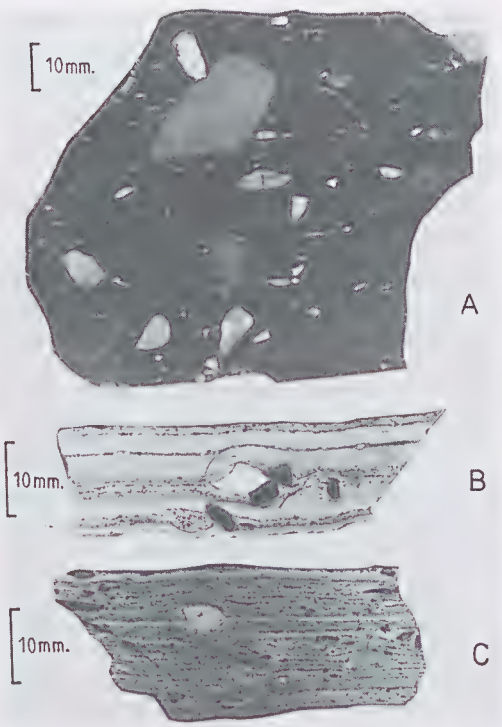

PLATE 2
(A) Polished slab of mixtite and (B,C) etched slabs of pebbly laminated dolomite, all from Cotcase Creek Formation. Note possible till clast in (B). Orientation uncertain.

At a southern locality (DN570487), mixtite is interlayered on a scale of metres to tens of metres with laminated pebbly dolosiltite. The dolosiltite is thinly planar-laminated, pale grey in colour and rich in detrital quartz sand and silt; it contains sparse floating granules, pebbles and rare cobbles of dolomite (pl. 2B,C). The laminae are deformed by differential compaction about these clasts. Some granules and small pebbles are clumped together in loose aggregates, a structure that resembles that of some till clasts (pl. 2B).

Also intercalated with the Cotcase Creek Formation are minor units of mudstone and siltstone, rare chert and rare quartz sandstone. In the

northwestern part of the outcrop area, in probably the younger parts of the formation, labile sandstone, quartz sandstone and chert become more prevalent (Turner *et al.* 1985).

Lithicwacke Sequences

(? Late Precambrian–Cambrian)

Juxtaposed with the Weld River Group in several northern localities are two, more or less distinct lithicwacke-dominated successions. Contacts between these two sequences and with the Weld River Group are faults or probable faults.

One sequence is clearly younger than the Weld River Group as it commonly contains detritus that appears to be derived from the latter. It overlies the Pandani Group with angular unconformity north and northwest of Mt Bowes; conglomerate at or near the base contains abundant, disoriented, cleaved clasts of Pandani Group derivation, as well as Weld River Group-derived clasts. Therefore, the sequence must unconformably overlie the Weld River Group as well. Quilty (1971) recorded a Middle or Upper Cambrian fauna at a nearby locality from rocks probably belonging to this sequence (Turner *et al.* 1985), and it is probably the same one which crops out extensively in the eastern foothills of Mt Mueller (not shown on fig. 1 but see Turner *et al.* 1985). The rocks are generally well-bedded and the lithicwackes are quartz-rich, with abundant metamorphic rock fragments, some dolomite rock fragments and very rare volcanic rock fragments.

The other lithicwacke-dominated succession crops out extensively in the upper Styx catchment (fig. 1). It contains pillow basalts and chert, and is associated with serpentinised ultramafic bodies. Stratification is massive or obscure, and lithicwackes contain common basaltic rock fragments, biotite and plagioclase, as well as metamorphic rock fragments. Metamorphic rock fragments in both sequences are schistose, suggesting derivation from the higher-grade Tyennan region to the west rather than from the Jubilee region. This latter, unfossiliferous lithicwacke sequence is of uncertain age but is thought to be also younger than the Weld River Group, due to its position in this regionally north-facing pile and its affinities being clearly with the middle Cambrian sequence rather than with the cratonic shallow-water Precambrian sequences.

The Middle or Upper Cambrian lithicwacke succession is a correlate of the Island Road Formation, while the other, volcanic-associated sequence appears to be a correlate of the Ragged Basin Complex (Turner 1989b).

DEPOSITIONAL ENVIRONMENTS

The older Precambrian sequences evidently experienced gentle tilting and erosion before Weld River Group sedimentation began. Proximal conglomerates were laid down on tilted Pandani Group basement while a thinner, finer-grained, more distal facies was deposited on the relatively undisturbed Jubilee Range sequence. Then followed a very great thickness of almost entirely carbonate sedimentation. If superposition of the Cotcase Creek Formation on the other units is assumed, then a total thickness of the order of 5 km for the Weld River Group is obtained. This estimate is necessarily highly imprecise because of the structural uncertainties previously mentioned.

As a rule, carbonate sedimentation requires a warm, shallow marine environment free of terrigenous influx (Wilson 1975). The depositional environments of the massive, fine-grained dolomites (Gomorrah, Styx and Cotcase Creek Formations) remain otherwise enigmatic. Grainstones in the Devils Eye Dolomite and at rare horizons elsewhere indicate a shallow and constantly agitated tidal shelf environment.

The mixtites of the Cotcase Creek Formation may be either tillites or mudflow deposits. Discrimination between these two modes of origin, although of great palaeoclimatological importance, is difficult (Schermerhorn 1974); no convincing proof of either mechanism has yet been found in the Cotcase Creek Formation. A debris-flow origin is favoured by the almost wholly intrabasinal provenance of the clasts, and the apparent lateral impersistence of some mixtite units. Observed variations in maximum clast size may be due to proximal settling of larger clasts during transport. No facetting or striation of clasts was observed but these would be difficult to identify, as matrix and clasts are equally indurated. The abruptness of the contacts and the general lack of a glacial imprint on the enclosing sequence also militate against a glacial origin. However, the pebbly laminated mudstone comprising the Lake Timk Formation and the rare pebbly laminated dolosiltite in the Cotcase Creek Formation are suggestive of a local glaciomarine imprint. Significant in this regard is the occurrence, at widespread localities elsewhere in Tasmania, of mixtites of possibly similar age (see below).

The juxtaposition of rocks of possible glacial origin with warm-water carbonates is a paradox that has been widely documented in late Precambrian sequences (e.g. Williams 1975). Although scarcely credible in uniformitarian terms, there is strong evidence to suggest that more or less abrupt changes from one climatic extreme to the other did occur at this time (Williams 1975).

RELATIVE AGE OF DEFORMATION

Two regionally significant phases of deformation have affected the Pandani Group and adjacent parts of the Weld River Group. The first (D_1) produced a first-order anticline in the Mt Anne–Mt Bowes area, plunging northwest and overturned to the northeast, with a pervasive axial planar slaty cleavage developed in pelitic rock types. The hinge zone lies within the Pandani Group (fig. 2), and the overturned part of the Weld River Group (that section exposed along the northeast ridge of Mt Anne) represents part of the overturned northeastern limb of this structure. S_1 cleavage is developed in siliciclastic units within the Weld River Group and is concordant across the unconformity (fig. 2). The second phase (D_2), coaxial with the first, produced a crenulation widespread in the Pandani Group but only locally developed in the Weld River Group.

East of the Weld River, the Precambrian rocks are only weakly deformed, with a weak bedding-parallel slaty cleavage (S_1?) affecting mudstones in both the Jubilee Range sequence and the Annakananda Formation correlate. There is also a locally developed weak crenulation associated with upright, northwest-trending minor folds in the Jubilee Range sequence.

Outcrop and thin-section examination of Annakananda Formation conglomerates in both the Mt Anne and Weld River localities reveal no predepositional cleavage in the constituent clasts, which in both areas appear to be derived from the underlying rocks. By contrast, the Middle or Upper Cambrian conglomerate north of Mt Bowes contains Pandani Group-derived clasts with a slaty cleavage that clearly pre-dates deposition of the conglomerate.

Thus, the earliest known and most significant deformation (D_1) affecting the Precambrian rocks of the northern Jubilee region is post-Weld River Group and pre-Upper Cambrian in age.

CORRELATION

The broad stratigraphic setting of the Weld River Group is similar to that of pre-middle Cambrian sequences widespread in western Tasmania, in which a dolomitic shallow-water sedimentary unit unconformably overlies predominantly siliciclastic Precambrian rocks and is succeeded by volcano-sedimentary sequences suggestive of deepening and basin instability. On this basis, the Success Creek Group (Brown 1986), the Ahrberg Group (Turner 1988), the Black River Dolomite–Forest Conglomerate sequence (Spry 1964, Brown 1989), possibly the Trowutta Breccia and underlying rocks (Jago 1981), and the Jane Dolomite (Spry & Zimmerman 1959) may be lithostratigraphic correlates of the Weld River Group. All these sequences have been correlated at one time or another (e.g. Spry 1962, Williams 1976). Most contain mixtites or sedimentary breccias (Griffin & Preiss 1976, Brown 1986, 1989, Jago 1981, Spry & Zimmerman 1959).

However, correlation of the Weld River Group with these sequences is inconsistent with the relative age of the Penguin Orogeny in the northwestern Tasmania sequences. The Black River Dolomite–Forest Conglomerate sequence and the Success Creek Group (but possibly not the Ahrberg Group: Turner 1988) unconformably overlie rocks deformed in the Penguin Orogeny (Williams 1976) but, as shown above, the unconformity at the base of the Weld River Group does not correspond to any comparable folding or cleavage-forming event in the underlying rocks.

Whether the Penguin Orogeny was felt as a significant event outside northwestern Tasmania is currently a matter of contention. Turner (1988, 1989a) regards the Penguin Orogeny as a fundamental benchmark event throughout the Tasmanian Precambrian. On the other hand, one interpretation of preliminary radiometric dating of metamorphic events (Adams *et al.* 1985) and some geological evidence (Brown 1989: 48) suggest that the structural history in northwestern Tasmania was different from the rest of Tasmania in pre-middle Cambrian times.

Under this latter scenario, correlation of the Weld River Group with the post-Penguin Orogeny sequences of northwest Tasmania is consistent with the known timing of tectonic phases. A diminished Penguin Orogeny perhaps caused the hiatus and local tilting prior to Weld River Group deposition. The main deformation in the northern Jubilee region Precambrian rocks (D_1 of this paper) may then be equivalent to the significant early Cambrian

event determined from metamorphic radiometric dates from the Tyennan region (Raheim & Compston 1977, Adams *et al.* 1985).

DISCUSSION

The Weld River Group constitutes a significant late Precambrian dolomite sequence that was, until recently, virtually unknown. The thickness of the Group indicates a substantially more complete succession than any of the proposed correlates in western and northwestern Tasmania. Work is continuing on mapping, stratigraphy, palaeoenvironments, and diagenesis of these rocks. Conclusive identification of glacigene rocks, with important stratigraphic and palaeoenvironmental implications, remains to be achieved.

If the correlation and relationships with isotopically dated metamorphic events postulated above are correct, then the age of the Weld River Group is bracketed below by the Penguin Orogeny (c. 725 m.y.) and above by the early Cambrian (c. 540–610 m.y.) event of Adams *et al.* (1985) and Raheim & Compston (1977). This age range invites comparison with the Late Adelaidean (750–570 m.y., Dunn *et al.* 1971) sequences of South Australia, which include significant tillites and shallow-water carbonates (*ibid.*).

It must be emphasised, however, that the suggested correlation of the Weld River Group with the Success Creek Group and its correlates in northwestern Tasmania remains tentative, being based on broad lithostratigraphic criteria and lacking any direct chronostratigraphic or biostratigraphic basis. In this context, selective isotopic dating within the Jubilee region would clarify relationships with other Tasmanian Precambrian sequences, where some measure of chronostratigraphic control already exists.

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REFERENCES

Adams, C.J., Black, L.P., Corbett, K.D. & Green, G.R., 1985: Reconnaissance isotopic studies bearing on the tectonothermal history of Early Palaeozoic and Late Proterozoic sequences in western Tasmania. *Aust. J. Earth Sci.* 32: 7–36.

Brown, A.V., 1986: Geology of the Dundas–Mt Lindsay–Mt Youngback region. *Bull. Geol. Surv. Tasm.* 62.

Brown, A.V., 1989. Eo-Cambrian–Cambrian. *In* Burrett, C.F. & Martin, E. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 47–83.

Calver, C.R., 1989. The Jubilee Region. *In* Burrett, C.F. & Martin, E. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 53–54.

Calver, C.R., McClenaghan, M.P., Turner, N.J., Brown, A.V., McClenaghan, J. & Boulter, C.A., in prep.: Pedder. *Geol. Atlas 1:50 000 ser. Explan. Rep.* Sheet 8112S. Tasm. Dep. Mines.

Corbett, K.D., 1970: Sedimentology of an Upper Cambrian flysch-paralic sequence (Denison Group) on the Denison Range, southwest Tasmania. Unpubl. Ph.D. thesis, Univ. Tasm.

Dunn, P.R., Thomson, B.P. & Rankama, K., 1971: Late Precambrian glaciation as a stratigraphic boundary. *Nature* 231: 498–502.

Griffin, B.J. & Preiss, W.V., 1976: The significance and provenance of stromatolitic clasts in a probable Late Precambrian diamictite in northwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 110: 111–127.

Hall, W.D.M., 1967: Report of geological investigations, S.W. Tasmania, E.L.13/65. Unpubl. rep. Broken Hill Pty Co. Ltd.

Hofmann, H.J., 1987: Paleoscene no.7: Precambrian biostratigraphy. *Geosci. Can.* 14: 135–154.

Jago, J.B., 1981: Possible Late Precambrian (Adelaidean) tillites of Tasmania. *In* Hambrey, M.J. & Harland, W.B. (Eds): *EARTH'S PRE-PLEISTOCENE GLACIAL RECORD*. Int. Geol. Correlation Programme, Project 38: Pre-Pleistocene Tillites.

Lewis, A.N., 1924: Notes on a geological reconnaissance of Mt Anne and the Weld River Valley. *Pap. Proc. R. Soc. Tasm.* (1923): 9–42.

Quilty, P.G., 1971: Cambrian and Ordovician dendroids and hydroids of Tasmania. *J. Geol. Soc. Aust.* 17: 171–190.

Raheim, A. & Compston, W., 1977: Correlations between metamorphic events and Rb-Sr ages in metasediments and eclogite from Western Tasmania. *Lithos* 10: 271–290.

Schermerhorn, L.J.G., 1974: Late Precambrian mixtites: glacial and/or non-glacial? *Am. J. Sci.* 274: 673–824.

SPRY, A.H., 1962: The Precambrian rocks. *In* Spry, A.H. & Banks, M.R. (Eds): *THE GEOLOGY OF TASMANIA. J. Geol. Soc. Aust.* 9: 107–126.

SPRY, A.H., 1964: Precambrian rocks of Tasmania, Part VI. The Zeehan–Corinna area. *Pap. Proc. R. Soc. Tasm.* 98: 23–48.

SPRY, A.H. & ZIMMERMAN, D., 1959: The Precambrian rocks of Tasmania, Part IV. The Mt Mullens area. *Pap. Proc. R. Soc. Tasm.* 93: 1–9.

TURNER, N.J., 1988: The Precambrian inliers and their possible relationships (abstract). *In* Turner, N.J. (Ed.): *THE GEOLOGY AND EVOLUTION OF THE LATEST PRECAMBRIAN TO CAMBRIAN ROCKS IN THE WESTERN TASMANIAN TERRANE*. Abstracts volume. Geol. Soc. Aust. (Tasm. Div.): 6–8.

TURNER, N.J., 1989a: Precambrian. *In* Burrett, C.F. & Martin, E. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 5–46.

TURNER, N.J., 1989b: The Adamsfield District. *In* Burrett, C.F. & Martin, E. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 168–174.

TURNER, N.J., CALVER, C.R., MCCLENAGHAN, M.D., MCCLENAGHAN, J., BROWN, A.V. & LENNOX, P.G., 1985: Pedder. *Geol. Atlas 1:50 000 ser.* Sheet 8112S. Tasm. Dep. Mines.

WILLIAMS, E., 1976: *Explanatory notes for the 1:500 000 structural map of pre-Carboniferous rocks of Tasmania: Tasman Fold Belt System in Tasmania*. Tasm. Dep. Mines.

WILLIAMS, G.E., 1975: Late Precambrian glacial climate and the Earth's obliquity. *Geol. Mag.* 112: 441–465.

WILSON, J.L., 1975: *CARBONATE FACIES IN GEOLOGIC HISTORY*. Springer-Verlag, New York.

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THE TASMANIAN BLACKBIRD ERADICATION PROGRAMME, 1941–47

by Eric R. Guiler

(with three tables)

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The European blackbird was introduced into Tasmania as early as 1827; by 1930 the bird was widely distributed and was becoming a pest to the small fruits industry. A bounty scheme, begun in 1941, resulted in the destruction of 79 298 birds and 21 848 eggs by 1946, but was ineffectual in eradication because it was too late in being introduced and was ill-conceived biologically. The birds may have contributed to the decline of the small fruits industry.
Key Words: blackbird, *Turdus*, Tasmania, eradication.

INTRODUCTION

The European blackbird, *Turdus merula*, is firmly established as a part of the Tasmanian fauna and is widespread throughout most of the State, being abundant in urban and fruit-growing areas. It is found in native habitats, extending to the West Coast.

The popularly accepted account of the initial introduction is that it was by a criminal act at Beaumaris Zoo, Hobart, on 14 August 1923, when a cage containing a variety of European birds was rifled. The more valuable species were stolen but the 12 blackbirds were allowed to go free, the wire of the roof of the cage being rolled back to facilitate this.

However, there is evidence to show that blackbirds were brought to Tasmania many years before that date. Lawson (1949) recorded that Capt. Langdon brought a shipment of dogs and birds, including blackbirds, from England in 1827. The birds were greeted with joy by the homesick settlers. A pair of blackbirds was brought in by a Mr Muston in 1834 (Ross 1835), the birds arriving in Hobart (Marine Board 1834).

Nothing is known of the fate of these birds or whether they were released into the wild, but the species ultimately became established. It would be hard to find a better environment for their success — abundant food in suburbia, vegetable farms and especially in the small fruit orchards; safe nesting and roosting sites available in the surrounding bush and in blackberry bushes; the winters are relatively mild. The spread of the birds may well have been rapid. It is, however, largely undocumented.

A nest with four eggs was found at Russell Plains near Launceston in December 1916 (Dove 1919). Lord (1919) drew attention to the fact that blackbirds were nesting in Tasmania and exhibited specimens at a Tasmanian Field Naturalists' Club meeting in 1920. The fact that he took the trouble to record their presence would indicate that they were not then very common. No attempt was made to kill or capture wild blackbirds or those which escaped from the Zoo in 1923; although Lord foresaw their danger to fruit-growers and urged the City Council in 1923 to destroy the birds, no action was taken (Guiler 1986). L. Wall (pers. comm.) has documentary evidence of their presence as far away as Port Davey by 1925. The Minutes of the Royal Society of Tasmania recorded, in May 1928, that blackbirds had been seen in the vicinity of the Hobart Botanical Gardens (Bryden 1966), suggesting that there were still not many in this area.

However, by 1930 there were sufficient blackbirds near Launceston for P. Eastoe of St Leonards to complain to the Fauna Board that they were eating his currants, strawberries and raspberries. He was told to ask the Agriculture Department to destroy them (Animal & Birds Protection Board (ABPB) 1930a).

In 1930 also, they were introduced to Flinders Island (Green 1969): two years later they were breeding there and built up in such numbers that by 1942 Messrs Goss and Dart lodged bounty claims

for some of them (Pest Account Book). They are now found there in the native ti-tree habitat (Green 1969).

The rapidity of the spread of blackbirds suggests that they may have been released in many places throughout the State. Dr W. Bryden (pers. comm.) has a strong recollection of Sir William Crowther telling him that his father liberated blackbirds in paddocks behind Burnie to control pasture pests.

OBSERVATIONS

The berry fruits industry, with an emphasis upon raspberries, was concentrated in the river valleys, particularly the Huon, D'Entrecasteaux Channel and Upper Derwent Valley districts, although there were also growing regions in the Tamar district and elsewhere in the north of the State. The berry farms were mostly small in size, 0.4–1.6 ha (1–4 acres), although a few were only 0.3 ha. Only 170 of the 1700 registered fruit farms were larger than 4 ha, while the largest (at Collinsvale) covered 27 ha (Register of Fruit Growers). The smaller holdings would be highly vulnerable to predation by blackbirds which found ready shelter in the adjacent scrub.

Matters relating to the fruit industry initially were the responsibility of the Small Fruits Advisory Committee from 1932–39, before the Stone and Berry Fruits Board (SBFB) was established under an Act of 1939. This Board soon became involved with the blackbird problem.

The Animals and Birds Protection Board (commonly known as the Fauna Board) was charged, among other things, with the protection of native fauna. It had no responsibility towards the eradication of other species, particularly where, as in this case, the Board had played no part in their introduction, although it had peripheral interest in the eradication campaign. Pest control was a function of the Department of Agriculture.

The presence of blackbirds was recognised as a threat to the export small fruit industry and the Government experts hoped, in 1928, to have them exterminated before they became a pest (Bryden 1966). The Fauna Board, which became concerned about the matter in 1929, drew the Government's attention to the existence of a colony of blackbirds, adding that these would become a menace to orchardists and that measures should be taken to exterminate the birds (ABPB 1930b). Some discussions ensued between the Board and the Department of Agriculture, resulting in the Board being led to believe that there was no need for it to do anything as the Government was going to take action.

A bounty scheme was introduced in May 1930 with a payment of 10 shillings per dead blackbird, an unrealistically large sum. By August about 200 birds must have been killed as no less than £100 had been paid out. Predictably, the scheme was abandoned as too expensive (ABPB 1930c).

The matter was left in the hands of the Department of Agriculture, but little, if anything more was done even when the Small Fruits Advisory Committee was set up in 1932. The Minutes of this Committee do not record any concern for the looming blackbird threat.

It was not until 1940, when the depredations of the blackbirds became more serious, that strong pressure was exerted for Government action to control them. The SBFB received from F. McDermott, M.H.A., a request for a bounty scheme, probably originating from someone else as McDermott was not a fruit-grower (Mr D. Dwyer, former head of the Attorney-General's Department, pers. comm.). The SBFB passed the request to the Department of Agriculture which organised a conference with the Fauna Board, the only concrete result of which action was that the Fauna Board published drawings for widespread display showing both sexes of blackbird and the eggs (ABPB 1940).

In the meantime the SBFB requested that the Government declare blackbirds noxious vermin (SBFB 1940). This would have involved landowners in an obligation to kill the birds if they were found on their properties. No action was taken on this request but, as the birds were always unprotected, they could be killed at any time.

The SBFB requested the Government, in 1941, to provide £500 as a special grant to fund a bounty scheme whereby sixpence would be paid for each bird's head and twopence for each egg and that it be made an offence for any person to refuse or neglect to eradicate blackbirds on their properties, with a penalty of £2 (SBFB 1941a). Both requests were agreed to by the Government but, rather significantly, it was noted that some of the community liked having these birds on their properties.

Another decision taken at this time was to offer a prize of 10 guineas for the best suggestion for eradicating the pest (SBFB 1941a) but subsequent Minutes are not clear as to who won the prize or the nature of the suggestions. Fauna Board member P. Wigg was one of the finalists.

The payment arrangements for the bounty were

the same as those used about 50 years earlier for thylacine bounties (Guiler 1985), the head or (in the case of the birds) the eggs to be produced to a Police Officer or other authorised person, who would issue a certificate to be presented to the Board for payment.

The Fauna Board commented as early as 1941 that the bounty scheme was useless, a statement described as nonsense by the SBFB. The Fauna Board requested in July 1941 that poisons not be used in the campaign (ABPB 1941b) and the SBFB agreed to this.

Other species were accidentally suffering in the campaign; general concern was expressed by the Tasmanian Field Naturalists' Club, specifically fearing that the eggs of the native thrush would be mistaken for those of the blackbird; colour drawings of the olive-green thrush and the blue blackbird eggs were therefore circulated (SBFB 1941c).

The Police Department, which handled most of the bounty claims, was tired of the whole business and the work involved, and recommended to the Fauna Board in 1942 that the bounty on eggs be discontinued as it encouraged disturbance of the nests of other species. The Department also suggested that, if the scheme were continued, the payment should be for the whole nest and not for the eggs (ABPB 1942). Nothing came of these proposals, but it may be significant that the request was made to the Fauna Board.

There appears to have been some niggling between the two Boards, perhaps started by the Fauna Board's comment on the validity of the scheme. The Minutes of both Boards show points of disagreement and this became evident when the SBFB, in 1942, requested the Government to give them representation on the Fauna Board (SBFB 1942a). The Minister promised to do this "whenever the opportunity presented itself" (SBFB 1943a). However, this never came to pass, partly because Fauna Board member P. Wigg was a fruit-grower and so could be said to represent their interests.

Fauna Board representatives attended a meeting of the SBFB on 4 November 1942 and formally requested the termination of the bounty scheme. One of these representatives, Dr Pearson, did not endear himself to growers by saying that the scheme as constituted was useless and that they should concentrate their efforts on killing the female blackbirds. The Fauna Board pressed the views of the Police Department that disturbance was being caused to the nests of other species (SBFB 1942b). The scheme continued, although an attempt was made to alter it by eliminating the egg bounty and replacing it with a reward of one shilling per adult bird and sixpence per fledgling, the reward to be paid only for birds from fruit-growing areas. These suggestions raised a storm of protest from the Municipalities and they were dropped (SBFB1943).

Although the scheme continued in 1944, the issue appeared less frequently in the Minutes of the SBFB and perhaps the bounty's most devoted advocates were beginning to feel that the results, although substantial, were not having much effect on blackbird numbers. The Minister for Agriculture visited the SBFB Meeting in May 1945 and said that he would place the request for the bounty money before Cabinet. This was unusual, as recurring expenditure is a departmental item which would not necessarily go to Cabinet for individual approval; it may imply that Cabinet or some members of it were objecting to allocating £500 per annum to a scheme of dubious value. The scheme continued until the 1946–47 Estimates, when the amount requested was reduced from £500 to £250. This was considered adequate to meet claims up to June 1947 and the SBFB was informed that no increase in this sum could be expected in the 1947–48 Budget (SBFB 1947a). (The Minutes of the Board from 1947 were not available.)

The number of birds and eggs destroyed is substantial and represents a lot of hunting effort (table 1). The breeding cycle of the blackbird coincides with the financial year (table 2) so that biologically valid data are available. The figures in table 1 differ from the annual totals in table 2, but no explanation can be offered for this, the material being given as in the sources.

More eggs than birds were destroyed in October, except in 1943–44, but the combined totals of birds and eggs destroyed were greatest in December and January. The season in 1945 may have been later than in other years, as the claims were not lodged in numbers until a month later than usual and continued at a high level for an additional month. The number of birds killed in 1944–45 shows a bimodality which is absent from all other years. The annual differences may be due to weather, economic conditions or wartime labour problems, apart from any biological factors which may be involved.

The large number of eggs submitted in December each year probably is the result of a second breeding as the first laying occurs two months or so earlier than this. I do not believe that the eggs were stockpiled, as the total number of eggs per claim

TABLE 1

Heads and Eggs of Blackbirds upon which Bounty was paid

Financial year	Birds	Eggs	Total	Cost £ s d
1941–42	19380	8709	28089	557 1 6
1942–43	18652	4457	23109	503 8 10
1943–44	16049	3531	19580	430 13 0
1944–45	12984	2360	15344	344 5 4
1945–46	12233	2791	15024	328 9 8
Totals	79 298	21 848	101 246	2163 18 4

Source: Minutes SBFB, 18 August 1946.

TABLE 2

Blackbirds and Eggs presented each Month for Bounty in Tasmania (1941–45)*

	Financial year							
	1941–42		1942–43		1943–44		1944–45	
Month	Birds	Eggs	Birds	Eggs	Birds	Eggs	Birds	Eggs
Jun	375	18	251	19	649	17	498	8
Jul	166	0	161	5	210	3	241	11
Aug	128	0	121	22	143	0	150	11
Sep	200	49	58	31	212	28	97	31
Oct	1197	1946	738	1045	474	391	166	227
Nov	2479	2443	1438	936	1325	1314	1111	733
Dec	5221	2868	5217	1474	3374	1074	1320	467
Jan	5896	916	3629	476	3668	396	3567	488
Feb	2151	285	4446	461	2714	143	1639	131
Mar	1184	123	1504	124	1638	102	2400	155
Apr	232	12	685	49	843	114	1120	37
May	277	33	309	20	730	43	na	na
Annual totals	19 506	8693	18 611	4662	15 980	3625	12 309	2299
Totals	66 406 birds, 19 279 eggs							

Source: Pest Account Cash Book, SBFB.
* Numbers obtained by conversion from amounts paid for each category.
na = not available.

TABLE 3

Average Number of Birds and Eggs per Claimant during the Tasmanian Blackbird Bounty (1941–45)

	Financial year							
	1941–42		1942–43		1943–44		1944–45	
Month	Birds	Eggs	Birds	Eggs	Birds	Eggs	Birds	Eggs
Jun	20.8	9.0	14.8	9.5	16.2	4.2	24.9	4.0
Jul	6.9	0	10.7	2.5	13.1	3.0	26.8	2.0
Aug	7.1	0	15.1	7.3	11.0	0	16.7	11.0
Sep	8.0	9.8	6.4	7.7	11.2	5.6	13.9	15.5
Oct	5.0	11.1	5.2	16.9	8.5	13.0	6.9	14.0
Nov	6.5	9.6	6.6	7.7	8.0	11.0	11.6	10.3
Dec	8.7	8.6	11.0	16.5	13.0	8.4	15.0	12.3
Jan	11.0	5.3	13.6	40.6	20.0	9.4	24.9	10.2
Feb	13.2	6.6	2.0	51.8	25.0	6.2	23.0	6.6
Mar	13.3	8.2	1.5	8.2	19.3	8.5	36.4	9.1
Apr	10.5	1.7	12.0	3.5	14.1	9.5	36.1	6.2
May	9.9	8.2	12.4	3.3	21.5	7.1	na	na
Annual average	10.07	7.81	9.28	14.56	15.1	7.16	21.44	9.21

na = not available.

does not support this view. It is more likely that they represent an effort at control being exerted as the fruit ripened.

DISCUSSION

Little is known of the population dynamics of the blackbird in Tasmania, although some comparisons can be made with English studies (Snow 1958, Lack 1966). Three to five eggs are laid per clutch and the birds usually raise two clutches per annum, with three being frequent. About 90% of the eggs hatch. Older parents are more successful than first-year birds and raise 6.3 young to the fledgling stage each year. The survival of the fledglings varies considerably in different habitats, as well as with the maturity of the parents and the seasonal conditions, but about 55% of them survive to independence and, of these, 16% successfully over-winter, i.e. about six out of every 100 fledglings. Once adult, they become subject to a 44% annual mortality rate which is the same for both sexes.

It is likely that the abundant food supply, milder winters and better Tasmanian conditions result in lower mortalities and better breeding rates, aided by the longer warm seasons. This means that more young birds must be killed to reduce future populations.

The data presented in table 2 suggest that a small number of birds may have bred all year around, although some of the eggs could have been collected outside the breeding season from long-abandoned nests.

Egg removal may have some effect upon the production of young, table 2 showing a substantial decline in the number of eggs taken from 1941 to 1947. However, it is more likely that this is a result of a decline in hundting interest, as the catch per unit of effort (table 3) shows an increase over the same period, indicating that little, if any, effect was being felt by the bird population.

Both birds and eggs were taken in an unorganised fashion in both rural and urban areas, irrespective of whether fruit was grown there or not. J. Napier (pers. comm.) told me that as a small boy he made pocket money from this source in the St Marys district, which is many kilometres from any fruit-growing areas.

Two annual competitions were held, in 1941 and

1942, with prizes for the largest number of eggs and birds caught by an individual. The largest number of birds were caught in orcharding areas at Nichols Rivulet (247) and Castle Forbes Bay (190) but most eggs were taken in both years by New Town residents (356 and 140) (SBFB 1943b).

The general impression is that too many claims were paid on birds from non-fruit-growing areas and that many of the birds killed would have died of natural causes later in the season.

There is no point in anaylsing the bounty data to assess the relative density of blackbirds in different parts of the State. The Pest Petty Cash Book showed that of the first 200 entries only 24 bounty receipts could be traced to their home address. These recipients killed 63 birds and took 69 eggs, whereas totals for the first 200 claims were 595 and 1081 respectively. It is believed that many of the claimants were small boys whose names would not appear in the usual sources such as Postal Directories. No valid conclusions could be based on such incomplete evidence.

Almost all the claims were for small numbers of birds or eggs, only 50% reaching double figures. This was adminstratively expensive and troublesome. Clearly there was no stockpiling of materials, which supports the theory that small boys formed the main part of the collecting force. It also suggests very strongly that there was no systematic approach towards the eradication of the pest in places where it was most harmful.

CAUSES OF FAILURE OF THE CAMPAIGN

Early literature tells us little of the pre-1930 distribution of blackbirds but it can be assumed that they spread from Hobart, probably from Launceston and possibly from other nuclei. In all instances humans were the method of establishment of the birds.

The primary cause of failure to eradicate or even partially control the blackbirds was that the killing commenced far too late after the problem became obvious. Had the warnings of Lord in 1919 and 1923 been heeded, or even the Fauna Board concern in 1930, there might have been some chance of control being gained, but by 1941 the birds were too widespread and numerous.

Once the birds became established, their melodious singing developed an affection for them in many people, so that any campaign for their eradication was foredoomed because of an absence of total community involvement or support.

To save costs, the bounty should have been aimed at one sex or the other; this was realised by the Fauna Board in their 1942 proposals which were rejected. It is usual to target the female but, in this instance, it probably would have been better to have selected the male, who is more conspicuous and, with his flamboyant breeding and territorial behaviour, would have presented better shooting. Since both parents are involved in rearing the young it makes little difference which one is absent.The robbing of nests was of little value as the female would begin laying a new clutch soon afterwards.

The methods of killing the birds were restricted by the banning of poisons and by wartime shortages of .22 calibre ammunition. The SBFB frequently requested the Munitions Board to release more supplies but to no avail.

Most of the bounties were paid in the interval October to March each season. This may have been because the birds were more conspicuous during the breeding season or because the fledgling young provide easy targets and can even be knocked down with sticks. The killing months also represent the concern of the grower for his developing crop and the need to protect it. The campaign would have been more effective had the breeding stock been reduced by a vigorous winter operation, particularly in the fruit-growing areas, with an increased bounty during that time.

The purpose of the bounty scheme was to relieve fruit-growers of the blackbird pest but the attempt to control the birds over the whole of the State did not achieve worthwhile results. The campaign was ill-conceived both biologically and administratively. There was little hope of eradicating blackbirds, but a touch of realism would have shown that more direction was needed than merely the setting up of such a scheme.

Economic factors and changing conditions after the war brought about a decline in the small fruits industry. The SBFB predicted that if the bounties were discontinued, it would be the end of the industry (SBFB 1947b). This prediction may have been an overstatement but there can be little doubt that the blackbirds did play a part in the industry's decline.

SOURCES

The sources used in preparing this were the Minutes of the Stone and Berry Fruits Board (SBFB); Pest Account Book of that Board, June 1941–April 1945; Minutes, Small Fruits Advisory Committee, 1932–36; Minutes, Animals and Birds

Protection Board 1928–47 (ABPB); Register of Fruit Growers. All of these are held in the State Archives of Tasmania.

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I am indebted to Mr L. Wall, Dr W. Bryden and Mr J. Napier for literature references and personal reminiscences.

REFERENCES

Animal & Birds Protection Board (ABPB) Minutes, 1930a: 2 Nov.; 1930b: 4 Apr., 6 May, 26 Aug.; 1930c: 17 May; 1931: 5 May; 1940: 2 Apr., 7 May; 1941a: 3 May; 1941b: 7 May; 1942: 27 Jul.

Bryden, W., 1966: Tasmanian Museum and Art Gallery: Historical note. *Pap. Proc. R. Soc. Tasm.* 100: 21–26.

Dove, H.S., 1919: The blackbird in Tasmania. *Emu* 19:70.

Green, R.H., 1969: Birds of Flinders Island. *Rec. Q. Vict. Mus.* 34: 1–32.

Guiler, E.R., 1985: *THYLACINE — THE TRAGEDY OF THE TASMANIAN TIGER*. Oxford University Press, Melbourne.

Guiler, E.R., 1986: The Beaumaris Zoo in Hobart. *Pap. Proc. Tasm. Hist. Res. Assoc.* 33(4) : 21–27.

Lack, D., 1966: The European Blackbird in gardens and woods. *BIRD POPULATION STUDIES*. Oxford University Press, London.

Lawson, W., 1949: *BLUE GUM CLIPPERS AND WHALE SHIPS OF TASMANIA*. D & L Books, Launceston.

Lord, C.E., 1919: Proceedings Meeting, 10 Nov. *Pap. Proc. R. Soc. Tasm.* (1920): 155.

Marine Board, 1834: Shipping arrivals in Hobart. State Archives of Tasmania, MB/2/39: 197.

Pest Account Petty Cash Book, undated. State Archives of Tasmania, CB 36/9.

Register of Small Fruit Growers, undated. State Archives of Tasmania, CB 36(4).

Ross, J., 1835: Chronological view of events in Van Diemen's Land in 1835. *TASMANIAN ALMANACK*. J. Ross, Hobart Town.

Small Fruits Advisory Committee, 1932–36: Minutes. State Archives of Tasmania, CB 36.

Snow, D.W., 1958: *A STUDY OF BLACKBIRDS*. Allen & Unwin, London.

Stone & Berry Fruits Board (SBFB) Minutes, 1940: 15 Nov., 17 Dec.; 1941a: 17 Jan.; 1941b: 9 Sept.; 1941c: 14 Oct.; 1941d: Nov.; 1942a: 25 Sept.; 1942b: 14 Nov.; 1943a: 7 Jan.; 1943b: 13 Apr.; 1947a: 20 Nov.; 1947b: 28 Mar.

(accepted 12 May 1989)

MACQUARIE HARBOUR, TASMANIA — SEASONAL OCEANOGRAPHIC SURVEYS IN 1985

by G. R. Cresswell, R. J. Edwards and B. A. Barker

(with three text-figures)

CRESSWELL, G.R., EDWARDS, R.J. & BARKER, B.A., 1989 (31:x): Macquarie Harbour, Tasmania — seasonal oceanographic surveys in 1985. *Pap. Proc. R. Soc. Tasm.* 123: 63–66. ISSN 0080–4703. CSIRO Division of Oceanography, Marine Laboratories, GPO Box 1538, Hobart, Tasmania, Australia 7001.

Seasonal oceanographic surveys of Macquarie Harbour suggested the existence of a three-layer system: a surface layer responsive to seasonal heating and cooling and to river runoff, a slowly changing mid-level layer, and (in the deeper basins) a marine layer fed by tides flooding over the sill.
Key Words: oceanographic survey, Macquarie Harbour, Tasmania.

INTRODUCTION

Macquarie Harbour in western Tasmania is one of Australia's largest estuaries. It has inputs from both nature and the activities of mankind — the sea, rivers and rainfall (1.8 m annually at the coast and 2.6 m in the highlands); mine slurry discharged into the King River for over a century and cold water discharged from turbines deep in the Gordon Dam. A recent review of the state of knowledge of the hydrological and hydrodynamic system of Macquarie Harbour found this to be "totally inadequate for making any statement on the environmental effects of any development projects which will physically alter the rivers or the harbour" (Waterman and Matthews, 1979).

1985 SURVEYS

The present study was modest in both effort and expense; it was designed to get an initial feeling for the seasonal variations of standard oceanographic water properties in the harbour. Four oceanographic surveys of the harbour and the Gordon River were made in January, March, July and October 1985, using a powered catamaran chartered from the National Parks and Wildlife Service; the Gordon River was monitored because of its importance as a source of fresh water for the harbour. As shown in figure 1, four stations were sited along the harbour axis (named according to the nearest landmark) and three on the river — "down-river" at the mouth of the Gordon River, "mid-river" 8 km upstream, and "up-river" 35 km upstream at Warners Landing. (The undammed Franklin River flows into the Gordon River 5 km upstream from Warners Landing.)

Nansen bottles (with reversing thermometers) were spaced at 2.5, 5 or 10 m depth intervals. The lead weights on the Nansen bottle wires were used for sounding at the stations. Water samples were analysed for salinity, oxygen, nitrate, and silicate content (Major *et al.* 1972).

The January and October surveys were each completed in one day. Both the others required part of an extra day because of bad weather on the March survey and bad weather and short daylight hours on the July survey.

The authors' conclusions about seasonal variations take no account of high frequency variations due to tides, passing weather patterns, varying flow through the Gordon Power Station, etc. However, the harbour is expected to have a long time constant as compared to, say, a river, so that the coarse temporal sampling used will be suitable for identifying gross seasonal variability.

RESULTS

Macquarie Harbour

The sections (fig. 2) and the temperature, salinity, and oxygen profiles at the Sophia stations (fig. 3) enable three layers to be identified in the harbour: (1) A surface layer in the upper 10 m, dominated by seasonal heating and cooling and river runoff. The annual surface temperature range at the Sophia station is nearly 10°C. The runoffs from the Gordon

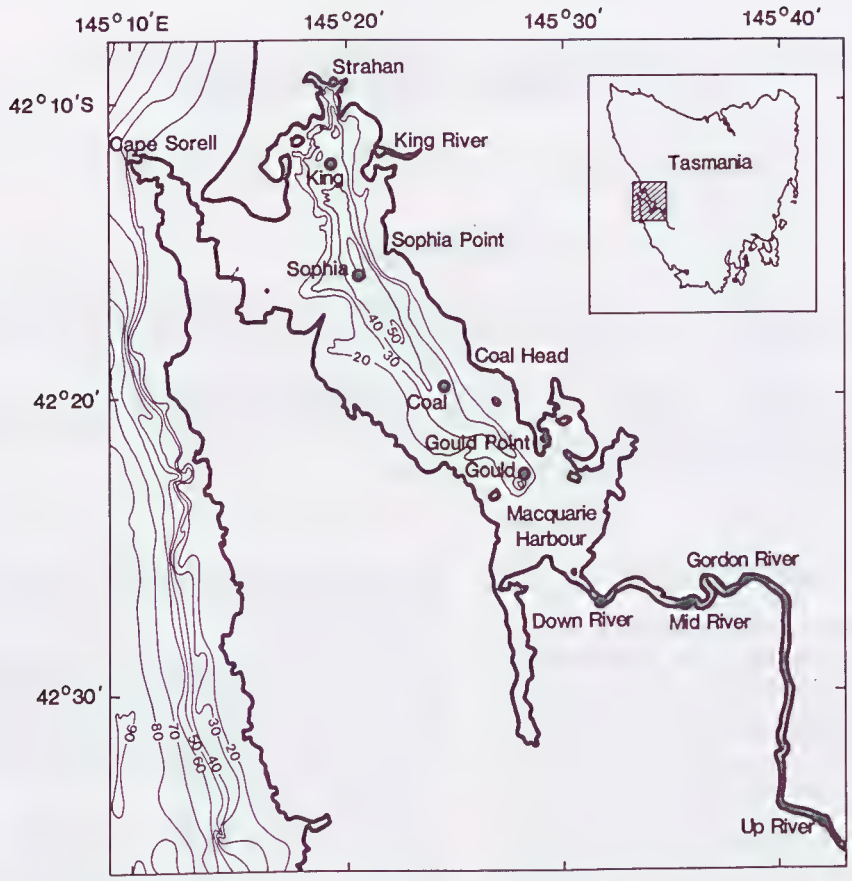

Fig. 1 — A chart of Macquarie Harbour and the Gordon River, showing the station positions.

River and, to a lesser extent, the King River brings waters low in salinity and high in oxygen and silicate into the harbour.

(2) A long-residence-time layer centred at about 20 m depth, having a small annual temperature range (0.8°C), low oxygen content and, in general, a peak in the nitrate content.

(3) A deep marine layer in which the salinity exceeds 31‰ and the oxygen content increases with depth. The annual variation of the temperature of this layer (1.5°C) has a phase similar to that of the ocean, being warmest in March and coldest in October. The layer is probably replenished by flood tides bringing in marine water, which is then modified by mixing across the harbour entrance before sinking to the deepest basins. The entrance to the harbour is about 7 m deep and the speed of the flood tide ranges from 2 to 6 knots (Waterman & Matthews 1979).

The Gordon River

The sections (fig. 2) revealed the Gordon River to be a source of fresh high-oxygen waters. The up-river station was mixed from top to bottom, with no sign of saline waters. The salt wedge always reached the mid-river station, where the maximum salinity was 20.8‰ in March.

DISCUSSION

A testable hypothesis arising from this work is that the water at about 20 m depth in the harbour has a long residence time and is low in oxygen. Above this, the water properties are controlled by runoff and seasonal heating and cooling, while below, in basins where depth exceeds 20 m, can be found marine water that has been modified by mixing.

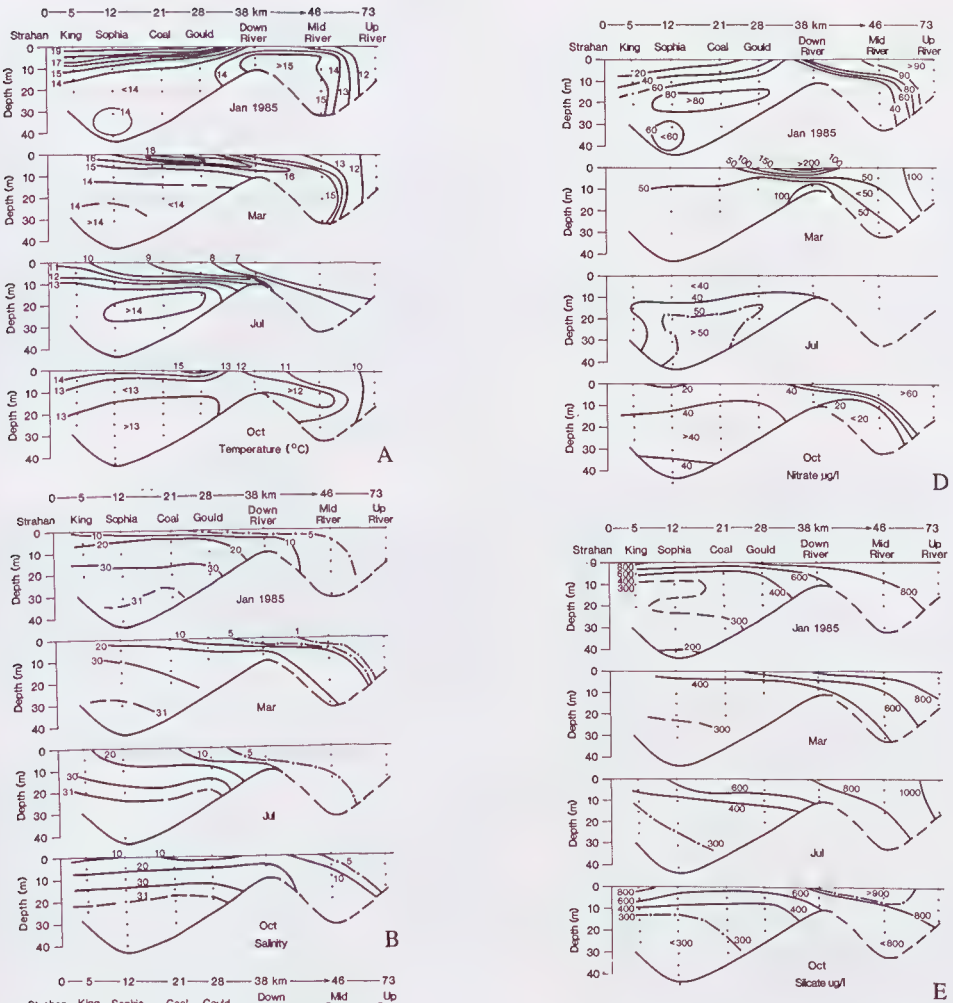

Fig. 2 — Sections along the axis of Macquarie Harbour and the Gordon River for the four surveys: (A) temperature, (B) salinity, (C) oxygen, (D) nitrate, (E) silicate.

Since 20 m is not an uncommon depth in the harbour, a large part of the harbour floor will be covered by water low in oxygen. The chemistry and biota may reflect this.

Waterman & Matthews (1979) took temperature and salinity profiles around the harbour on four days in early September 1979. Their temperature section along the harbour axis was very similar to that for July 1985, except that it was restricted to 26 m depth by the length of their instrument cable. The salinities measured at these depths were lower

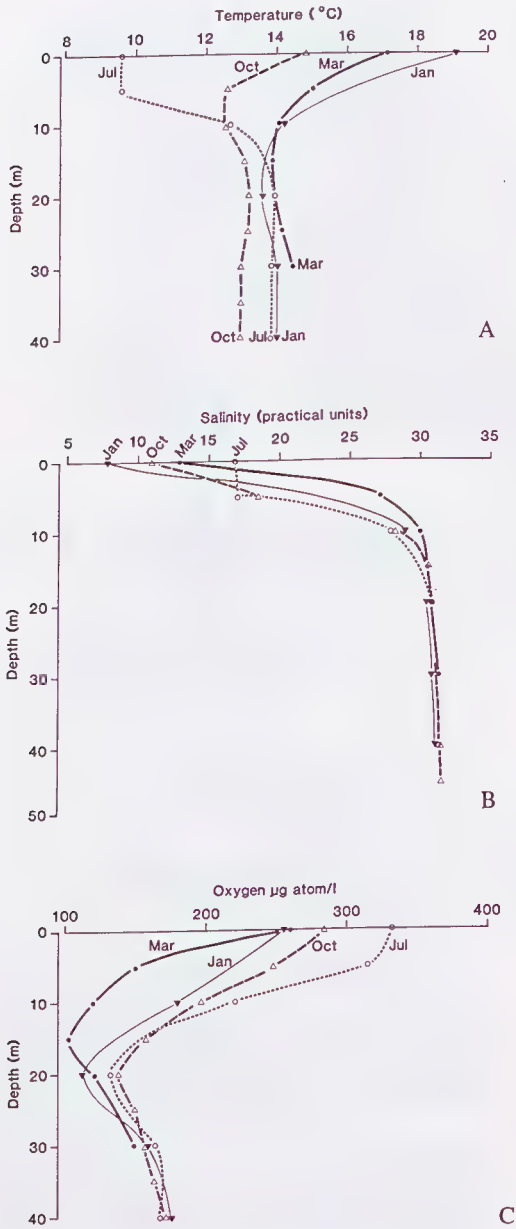

Fig. 3 — Profiles for the four surveys at the Sophia station for (A) temperature, (B) salinity, and (C) oxygen.

(27‰) than the value of 31‰ measured on all four of these 1985 surveys.

In the Gordon River, the salt wedge was always present at the mid-river station. Kearsley (1978) found that the length and depth of the wedge depended almost entirely on the flow in the river and concluded that in high flows the salt wedge would be almost entirely flushed out of the river. King & Tyler (1981) have expressed a concern that the controlled flow from the Gordon River Power Station prevents the natural upstream excursions of the salt wedge, which are probably essential to provide salt water to the meromictic lakes along the river. Certainly, the salinities at the mid-river station 8 km from the mouth were much less (20‰ versus 30+‰) than the pre-dam values reported by Kearsley (1978).

CONCLUSIONS

The series of surveys along the harbour axis has proven useful in identifying gross seasonal variations. The biological implications of the apparent long-residence-time, low-oxygen layer at mid-levels could be a fruitful subject for future study.

ACKNOWLEDGEMENTS

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REFERENCES

KEARSLEY, B.V., 1978. *THE PHYSICAL BEHAVIOUR OF SALINE WATER IN THE GORDON RIVER ESTUARY.* Lower Gordon River Scientific Survey, Hydro-Electric Commission, Hobart.

KING, R.D. & TYLER, P.A., 1981. Meromictic lakes of South-west Tasmania. *Aust. J. Mar. Fresh. Res.* 32: 741–756.

MAJOR, G.A., DAL POINT, G., KLYE, J. & NEWELL, B., 1972. Laboratory techniques in marine chemistry. A manual. *CSIRO Aust. Div. Fish Oceanogr. Rep.* No. 51.

WATERMAN, P. & MATTHEWS, J.H., 1979. A Review of Information on the Macquarie Harbour Environment. *SWTRS Discussion Paper* No. 20, NPWS, Hobart.

(accepted 10 February 1989)

A CHECKLIST OF TASMANIAN LICHENS

by Gintaras Kantvilas

KANTVILAS, G., 1989 (31:x): A checklist of Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* 123: 67–85. ISSN 0080–4703. Tasmanian Herbarium, GPO Box 252C, Hobart, Tasmania, Australia 7001.

This list records 633 lichen species plus 22 infraspecific taxa in 173 genera from Tasmania and the Bass Strait islands. Fourteen species are new records for Tasmania: *Arthroraphis citrinella*, *Cetraria australiensis*, *Coccotrema porinopsis*, *Hyperphyscia adglutinata*, *Lecanora blanda*, *Neofuscelia verrucella*, *Pertusaria superba*, *Phaeographis australiensis*, *Relicina subnigra*, *Rinodina bischoffii*, *Siphulastrum mamillatum*, *Sphaerophorus imshaugii*, *Stereocaulon gregarium* and *Usnea contexta*. A list of deleted names based on unreliable sources, misidentifications or misinterpretations of early literature is also provided.

Key Words: lichens, Tasmania.

INTRODUCTION

The last checklist dealing exclusively with the lichen flora of Tasmania was published by Wetmore (1963). That work cited all the hitherto published records of Tasmanian species (primarily from 19th-century literature) and listed 421 species in 82 genera. The last two decades have seen a major resurgence in lichenology, and many significant advances in the taxonomy of the Tasmanian flora have hastened the need for a new checklist. For example, many genera and families in the Australian region have been recently revised, including the Caliciales (Tibell 1987), *Cladia* (Filson 1981), *Cladonia* sect. *Cocciferae* (Archer 1988a), *Haematomma* (Rogers 1982, 1985), *Heterodea* (Blackman *et al.* 1973, Filson 1978), *Hypogymnia* (Elix 1979), *Knightiella* (Galloway & Elix 1980), *Leioderma* (Galloway & Jorgensen 1987), *Nephroma* (White & James 1988), *Pannoparmelia* (Bratt *et al.* 1976, Galloway 1978), *Parmelia* (Filson 1982, Galloway & Elix 1983, 1984), *Peltula* (Filson 1988a), *Pyxine* (Rogers 1986), *Ramalina* (Stevens 1987), *Rinodina* (Mayrhofer 1984), *Teloschistes* and *Xanthoria* (Filson 1969), *Umbilicaria* (Blackman *et al.* 1974) and *Xanthoparmelia* (Elix *et al.* 1986). Similarly, unpublished work by A.W. Archer and by D. Verdon has helped to clarify the genera *Cladonia* and *Leptogium* respectively.

Corresponding studies on the New Zealand lichen flora have also had a profound influence on Tasmanian lichenology in revising the taxonomy of many genera which are important in Tasmania. This work includes the pioneer studies of H.H. Allan, W. Martin and J. Murray (see Galloway 1974) as well as more recent work, e.g. *Arthroraphis* (Galloway & Bartlett 1986), *Baeomyces* (Galloway 1980a), *Cladonia* (Archer & Bartlett 1986), *Coccocarpia* (Arvidsson & Galloway 1979), the Graphidaceae (Hayward 1977), *Lobaria* (Galloway 1981), *Pseudocyphellaria* (Galloway 1983a, 1985a, 1988; Galloway & James 1977, 1980; Galloway *et al.* 1983; Wilkins & James 1979), *Rinodina* (Mayrhofer 1983), *Stereocaulon* (Galloway 1980b), *Thysanothecium* (Galloway & Bartlett 1983), *Xanthoparmelia* (Galloway 1980c) and the recent *Flora of New Zealand: Lichens* (Galloway 1985b).

Collections from Tasmania have also figured in some recent world monographs, e.g. *Cetraria* (Kärnefelt 1979), *Chrysothrix* (Laundon 1981), *Cladina* (Ahti 1961, 1984), *Coccocarpia* (Arvidsson 1982), *Collema* (Degelius 1974), *Degelia* (Arvidsson & Galloway 1981), the Megalosporaceae (Sipman 1983, 1986), *Metus* (Galloway & James 1987), *Parmelia* (Esslinger 1977, Hale 1988), *Pseudoparmelia* (Hale 1976), *Psoromidium* (Galloway & James 1985), *Relicina* (Hale 1975), *Sphaerophorus* (Ohlsson 1974, Tibell 1987) and *Usnea* subgen. *Neuropogonon* (Walker 1985), as well as in the studies on *Alectoria* (Hawksworth 1972), *Cladonia* (Ahti 1980) and *Gymnoderma* (Yoshimura 1973). This current work is based both on a review of existing 19th-century collections and the study of more recent collections.

New taxa from Tasmania have been published in recent years in the genera *Acarospora* and *Catillaria* (Räsänen 1944), *Arthonia* (Kantvilas & Vezda 1988), *Canoparmelia* (Elix & Johnston 1988), *Cladia* (Kantvilas & Elix 1987), *Cladonia* (Archer 1982, 1984, 1985, 1986, 1987, 1988b), *Diploschistes* (Lumbsch 1987), *Lichina* (Henssen 1969), *Lopadium* (Döbbeler *et al.* 1985), *Menegazzia* (Kantvilas & James 1987), *Parmelina* (Elix & Johnston 1986), *Psoroma* (James &

Henssen 1975), *Pycnothelia* (Galloway & James 1987), *Ramalina* (Stevens 1986), *Roccellina* (Tehler 1983), *Roccellinastrum* (Henssen *et al.* 1982), *Sarrameana* (Vezda & Kantvilas 1988), *Siphula* (Kantvilas 1987), *Stereocaulon* (Galloway *et al.* 1976), *Xanthoparmelia* (Elix & Johnston 1987) and *Vezdaea* (Döbbeler 1981), whilst the new Tasmanian genera *Conotremopsis* and *Wawea* were published by Vezda (1977) and Henssen & Kantvilas (1985) respectively. Additional new taxa from New Zealand (Galloway 1983b, Martin 1962) also have particular relevance to Tasmania, as do the new species from the Australian mainland published by Archer (1980), Elix (1981a,b), Elix & Johnston (1986), Elix & Stevens (1979), Elix & Armstrong (1983), Filson (1984) and Timdal (1984). New records for Tasmania are given by Bratt & Cashlin (1975, 1976), Filson (1986, 1988b), Filson & Rogers (1979), Elix & Streimann (1982), Hertel (1987), Kantvilas (1985), Kantvilas & James (1987 and in prep.), Kantvilas & Jarman (1988), Kantvilas *et al.* (1985), Lumbsch (1988a) and Petersen & Kantvilas (1986).

Although many of these developments have been incorporated by Filson (1983, 1986, 1988b) into his checklists of the Australian flora, there is considerable argument for maintaining the data for Tasmania separately. Firstly, Tasmania represents a distinct geographical entity and the phytogeographic affinities of its lichen flora are unique. These affinities are lost when subsumed within the data for a land mass as large and diverse as the Australian continent. Secondly, the increasing importance of lichens in the management and conservation of vegetation systems in Tasmania has generated considerable local demand for a checklist of the island's lichen flora.

It must be emphasised that the present paper does not represent a complete account of this flora. The state of knowledge within different genera and families remains patchy; hence the checklist is a blend of data from recent studies (see above) and information which has remained virtually unchanged since the list of Wetmore (1963), (e.g. in the genera *Peltigera*, *Pertusaria*, *Physcia*, *Sticta*, *Usnea*). Within these limitations, it represents a *status quo* report which will be updated as new information comes to hand.

METHODS

Names of all lichens previously reported from Tasmania, either in Wetmore (1963) or in subsequent papers (see above), are listed either in the checklist (if they are currently accepted) or in the list of excluded names. As far as practicable, original sources were checked in order to eliminate those records which have arisen through misinterpretation of the original reference. Names which are accepted but which are based solely on uncertain, mostly 19th-century records are followed by a (+). Taxa based on a Tasmanian type specimen are in bold type whilst taxa known only from the Bass Strait islands and not recorded from the Tasmanian mainland are listed in square brackets.

RESULTS

The present checklist contains 633 species plus 22 infraspecific taxa in 173 genera. Twenty-three taxa are known only from the Bass Strait islands. Fourteen species are recorded from Tasmania for the first time, based chiefly on the author's recent collections. These are: *Arthroraphis citrinella*, *Cetraria australiensis*, *Coccotrema porinopsis*, *Hyperphyscia adglutinata*, *Lecanora blanda*, *Neofuscelia verrucella*, *Pertusaria superba*, *Phaeographis australiensis*, *Relicina subnigra*, *Rinodina bischoffii*, *Siphulastrum mamillatum*, *Sphaerophorus imshaugii*, *Stereocaulon gregarium* and *Usnea contexta*. The checklist also includes some non-lichenised fungal genera which have been traditionally associated with the lichens, both taxonomically and ecologically, e.g. *Chaenothecopsis*, *Mycocalicium* and *Lichenothelia*.

CHECKLIST OF TASMANIAN LICHENS

Acarospora citrina (Taylor) Zahlbr. ex Rech.
***A. tasmanica* Räsänen**

Alectoria nigricans (Ach.) Nyl.

***Arthonia apteropteridis* Kantvilas & Vezda**
A. cinereopruinosa Schaerer *s. lat.*
A. cinnabarina (DC.) Wallr. (+)
A. complanata Fée (+)
A. epipastoides Leighton (+)
A. miserula Nyl. (+)
A. tumidula (Ach.) Ach. (+)

Arthopyrenia sublitoralis (Leighton) Arnold (+)

Arthothelium ilicinum (Taylor) P. James
A. interveniens (Nyl.) Zahlbr.
A. macrothecium (Fée) Massal. (+)

Arthroraphis alpina (Schaerer) R. Sant.
A. citrinella (Ach.) Poelt

***Austroblastenia pauciseptata* (Shirley) Sipman**
A. pupa Sipman

Bacidia buchananii (Stirton) Hellbom
B. leucocarpa Knight (+)
B. luteola (Schrader) Mudd (+)
***B. melasemoides* (Jatta) Zahlbr.**
[*B. millegrana* (Taylor) Zahlbr. (+)]
***B. otagoensis* (Nyl.) Hellbom var. *tasmanica* (Jatta) Zahlbr.**
***B. weymouthii* (Shirley) Zahlbr.**

Bactrospora dryina (Ach.) Massal.

Baeomyces absolutus Tuck.
B. arcuatus Stirton
***B. heteromorphus* Nyl. ex Church. Bab. & Mitten**

Bellemerea alpina (Sommerf.) Clauz. & Roux

***Biatora byssacea* Hampe**

Blastenia carnella (Nyl.) Müll. Arg. (+)
B. pulcherrima Müll. Arg.

[*Buellia coniops* (Wahlenb. ex Ach.) Th. Fr.] (+)
B. disciformis (Fr.) Mudd (+)
***B. levieri* Jatta**
[*B. subalbula* (Nyl.) Müll. Arg.] (+)

Calicium abietinum Pers.
***C. adspersum* Pers. ssp. *australe* Tibell**
C. glaucellum Ach.
C. salicinum Pers.
C. trabinellum (Ach.) Ach.
C. tricolor F. Wilson
C. victorianum ssp. (F. Wilson) Tibell *victorianum*
Caloplaca cerinella (Nyl.) Flagey (+)
C. chrysophthalma Degelius (+)
C. cinnabarina (Ach.) Zahlbr. (+)
C. citrina (Hoffm.) Th. Fr. (+)
***C. cribrosa* (Hue) Zahlbr.**
C. ferruginea (Huds.) Th. Fr. (+)
C. flavorubescens (Huds.) Laundon (+)
C. holocarpa (Hoffm.) Wade (+)
C. rugulosa (Nyl.) Zahlbr. (+)
C. saxicola (Hoffm.) Nordin (+)
C. sublobulata (Nyl.) Zahlbr. (+)

Candelariella reflexa (Nyl.) Lettau

Canoparmelia norpruinata Elix & Johnston

Catapyrenium lachneum (Ach.) R. Sant.

***Catillaria grossulina* (Stirton) Zahlbr.**
C. kelica (Stirton) Zahlbr.
***C. tasmanica* Räsänen**
C. trachonoides (Nyl.) Zahlbr. (+)
***C. umbratilis* Jatta**

Catinaria grossa (Pers. ex Nyl.) Vainio
C. laureri (Hepp ex Th. Fr.) Degelius
C. pulverea (Borrer) Vezda & Poelt

Cetraria australiensis W. Weber ex Kärnef.
C. chlorophylla (Willd.) Vainio
C. islandica (L.) Ach. ssp. *antarctica* Kärnef.

Chaenotheca brachypoda (Ach.) Tibell
C. brunneola (Ach.) Müll. Arg.
C. carthusiae (Harm.) Lettau
C. chrysocephala (Turn. ex Ach.) Th. Fr.
C. ferruginea (Turn. ex Sm.) Migula
C. gracillima (Vainio) Tibell
C. hispidula (Ach.) Zahlbr.
C. stemonea (Ach.) Müll. Arg.
C. trichialis (Ach.) Th. Fr.

Chaenothecopsis debilis (Turn. & Borrer ex Sm.) Tibell
C. haematopus Tibell
C. nigra Tibell
C. pusilla (Ach.) A. Schmidt
C. sagenidii Tibell
C. savonica (Räsänen) Tibell
***C. tasmanica* Tibell**
C. viridireagens (Nádv.) A. Schmidt

Chiodecton colensoi (Massal.) Müll. Arg.

Chrysothrix candelaris (L.) Laundon

Cladia aggregata (Sw.) Nyl.
***C. fuliginosa* R. Filson**

***C. inflata* (F. Wilson) D. Galloway**
***C. moniliformis* Kantvilas & Elix**
***C. retipora* (Labill.) Nyl.**
***C. schizopora* (Nyl.) Nyl.**
C. sullivanii (Müll. Arg.) Martin

Cladina confusa (R. Sant.) Follm. & Ahti
C. mitis (Sandst.) Hustich
***C. tasmanica* (Ahti) Ahti**

Cladonia angustata Nyl.
C. bimberiensis Archer
C. capitellata (J.D. Hook. & Taylor) Church. Bab. var. *capitellata*
C. capitellata var. *interhiascens* (Nyl.) Sandst.
C. capitellata var. *squamatica* Archer
C. cervicornis ssp. *verticillata* (Hoffm.) Ahti
C. chlorophaea (Flörke) Sprengel
***C. coniodendroides* F. Wilson** (type material not located, species unknown)
C. corniculata Ahti & Kashiwadani
C. cornuta (L.) Hoffm.
C. crispata (Ach.) Flotow
C. cryptochlorophaea Asahina
C. ecmocyna Leighton
C. fimbriata (L.) Fr.
C. floerkeana (Fr.) Flörke
C. furcata (Huds.) Schrader
C. gracilis (L.) Willd. ssp. *tenerrima* Ahti
C. humilis (With.) Laundon var. *humilis*
C. humilis var. *bourgeanica* Archer
C. krempelhuberi Vainio
C. kuringaiensis Archer
C. merochlorophaea Asahina
C. murrayi W. Martin
C. ochrochlora Flörke
C. paeminosa Archer
C. pertricosa Krempelh.
C. pleurota (Flörke) Schaerer
C. praetermissa Archer
C. pyxidata (L.) Hoffm.
C. ramulosa (With.) Laundon
C. rigida (J.D. Hook. & Taylor) Hampe var. *rigida*
C. rigida var. *acuta* (Taylor) Archer *ined.*
C. sarmentosa (J.D. Hook. & Taylor) Dodge
C. scabriuscula (Delise) Leighton
C. southlandica W. Martin
C. staufferi des Abb.
C. subdigitata Vainio
C. sulcata Archer var. *sulcata*
C. sulcata var. *wilsonii* (Archer) Archer
C. tessellata Ahti & Kashiwadani
***C. weymouthii* F. Wilson ex Archer**

Clathroporina eminentior (Nyl.) Müll. Arg. (+)

Cliostomum griffithii (Sm.) Coppins

Coccocarpia erythroxyli (Sprengel) Swinsc. & Krog
C. palmicola (Sprengel) Arvidsson & D. Galloway

Coccotrema cucurbitula (Mont.) Müll. Arg.
C. porinopsis (Nyl.) Imshaug ex Yoshimura

Coelocaulon aculeatum (Schreber) Link

Coenogonium implexum Nyl.

Collema coccophorum Tuck.
C. crispum (Huds.) Weber
C. durietzii Degelius
C. fasciculare (L.) Wigg. var *fasciculare*
C. fasciculare var. *colensoi* Church. Bab.
C. flaccidum (Ach.) Ach.
C. glaucophthalmum Nyl. var. *glaucophthalmum*
C. glaucophthalmum var. *implicatum* (Nyl.) Degelius
C. laeve J.D. Hook. & Taylor var. *laeve*
C. laeve var. *senecionis* (F. Wilson) Degelius
***C. leucocarpum* J.D. Hook. & Taylor**
C. quadriloculare F. Wilson var. *quadriloculare*
***C. quadriloculare* var. *tasmaniae* F. Wilson**
C. subconveniens Nyl.
C. subflaccidum Degelius

***Conotremopsis weberiana* Vezda**

Crocynia gossypina (Sw.) Massal. (+)

Cystocoleus niger (Huds.) Hariot

Degelia durietzii Arvidsson & D. Galloway
D. gayana (Mont.) Arvidsson & D. Galloway

Dendriscocaulon dendriothamnodes Dughi in D. Galloway

Dictyonema sericeum (Sw.) Berkley

Dimerella lutea (Dickson) Trevis.

Diploicia canescens (Dickson) Massal.

Diploschistes muscorum (Scop.) R. Sant ssp. *bartlettii* Lumbsch
D. ocellatus (Vill.) Norman
D. scruposus (Schreber) Norman
D. sticticus (Körber) Müll. Arg.

[*Diplotomma alboatrum* (Hoffm.) Flotow (+)]

Dirinaria picta (Sw.) Clem. & Shear

Ephebe fruticosa Henssen (type locality erroneously given as Grosse River, Tasmania by Henssen (1963); locality is in N.S.W.
E. lanata (L.) Vainio

Eremastrella crystallifera (Taylor) G. Schneider

[*Flavoparmelia euplecta* (Stirton) Hale]
F. haysomii (Dodge) Hale
***F. rutidota* (J.D. Hook. & Taylor) Hale**
[*F. soredians* (Nyl.) Hale]

Fulgensia fulgens (Sw.) Elenkin (+)
F. subbracteata (Nyl.) Poelt (+)

Fuscidea absolodes (Nyl.) Hertel & V. Wirth

Graphis angustata Eschw. (+)
G. insidiosa (Knight & Mitten) J.D. Hook.
G. scripta (L.) Ach.

Gyalecta jenensis (Batsch) Zahlbr. (+)

Gyalidea hyalinescens (Nyl.) Vezda

Haematomma infuscum (Stirton) R.W. Rogers
H. sorediatum R.W. Rogers

Heterodea muelleri (Hampe) Nyl.

Heterodermia comosa (Eschw.) Follm. & Redon (+)
[*H. hypoleuca* (Ach.) Trevis. (+)]
[*H. japonica* (Sato) Swinsc. & Krog. (+)]
H. microphylla (Kurok.) Swinsc. & Krog
H. obscurata (Nyl.) Trevis.
H. speciosa (Wulf.) Trevis. (+)

Hyperphyscia adglutinata (Flörke) Mayrhofer & Poelt

Hypocenomyce australis Timdal
H. foveata Timdal

***Hypogymnia billardierei* (Mont.) R. Filson**
H. enteromorphoides Elix
H. kosciuskoensis Elix
H. lugubris (Pers.) Krog var. *lugubris*
H. lugubris var. *compactior* (Zahlbr.) Elix
***H. lugubris* var. *sublugubris* (Müll. Arg.) Elix**
***H. mundata* (Nyl.) Rassad.**
***H. pulverata* (Nyl.) Elix**
H. subphysodes (Krempelh.) Filson var. *subphysodes*
H. subphysodes var. *austerodioides* Elix
H. tubularis (Taylor) Elix
H. turgidula (Bitter) Elix

Hypotrachyna laevigata (Sm.) Hale (+)
H. reducens (Nyl.) Hale
H. revoluta (Flörke) Hale
H. sinuosa (Sm.) Hale

***Knightiella splachnirima* (J.D. Hook. & Taylor) Gyelnik**

***Laurera megasperma* (Mont.) Zahlbr. var. *tasmanica* (Jatta) Zahlbr.**

Lecanactis abietina (Ach.) Körber
L. subfarinosa (Knight) Hellbom (+)

***Lecania vallatula* Jatta**

***Lecanora atrella* Jatta**
L. blanda Nyl.
L. broccha Nyl.
L. caesiorubella Ach. (+)
L. carpinea (L.) Vainio (+)
L. cenisia Ach. (+)
L. lineolata Müll. Arg. (+)
L. rupicola (L.) Zahlbr. (+)
L. subfusca (L.) Ach. (+)
[*L. varia* (Hoffm.) Ach. (+)]

***Lecidea aniptiza* Stirton f. *intersociella* Stirton**
L. canorufescens Krempelh. (+)
***L. cera-rufa* (Shirley) Zahlbr.**
L. contigua Fr. (+)
L. coromandelica Zahlbr.
L. elabens Fr. (+)
L. enteroleuca Ach. (+)
***L. flindersii* Crombie**
***L. hypersporella* Stirton**
L. hypnorum Libert
L. immarginata R. Br. ex Crombie
***L. laeta* Stirton**
***L. lampra* Stirton**
***L. leptocarpa* Nyl. ex Church. Bab. & Mitten**
L. leptoloma Müll. Arg. (+)
L. minutula Müll. Arg. (+)
***L. stuartii* Hampe**
***L. subnexa* Stirton**
***L. subtecta* Stirton**
L. turgidula Fr. (+)

Lecidella elaeochroma (Ach.) Choisy

Leioderma amphibolum (Knight) D. Galloway & P.M. Jørg.
L. duplicatum (Müll. Arg.) D. Galloway & P.M. Jørg.
L. pycnophorum Nyl.
L. sorediatum D. Galloway & P.M. Jørg.

Lepraria incana (L.) Ach.
L. lobificans Nyl.

Leprocaulon arbuscula (Nyl.) Nyl.
L. microscopicum (Vill.) Gams ex D. Hawksw.

Leproloma membranacea (Dickson) Vainio

Leptogium biloculare F. Wilson
L. coralloideum (May. & Flot.) Vainio
L. cyanescens (Ach.) Körber
L. limbatum F. Wilson
L. menziesii (Sm. ex Ach.) Mont.
L. pecten F. Wilson
***L. tasmanicum* F.Wilson**
L. victorianum F. Wilson

Leptotrema lepadodes (Tuck.) Zahlbr. (+)
***L. lepadodes* var. *endochrysoides* (Jatta) Zahlbr.**

[***Lichenothelia solitarioides*** **Henssen**]

Lichina confinis (O.F. Müll.) Agardh
L. tasmanica **Henssen**

Lobaria scrobiculata (Scop.) DC.

Lopadium biferum (Nyl.) Zahlbr. (+)
L. disciforme (Flotow) Poelt & Vezda
L. hepaticola **Döbbeler, Poelt & Vezda**

Maronea constans (Nyl.) Hepp

Megaloblastenia marginiflexa (J.D. Hook. & Taylor) Sipman

Megalospora biclipea **(Shirley) Zahlbr.** (type lost (Kantvilas 1988); best referred to *Catinaria s. lat.*
M. campylospora (Stirton) Sipman
M. gompholoma (Müll. Arg.) Sipman ssp. fuscolineata Sipman
M. lopadioides **Sipman**
M. subtuberculosa (Knight) Sipman

Melampilidium metabolum (Nyl.) Müll. Arg. (+)

Melanelia subglabra (Räsänen) Esslinger

Melaspilea circumserpens **Nyl.**
M. gemella (Eschw.) Nyl. (+)

Menegazzia aeneofusca (Müll. Arg.) R. Sant.
M. bullata (Stirton) Bitter.
M. caesiopruinosa **P. James**
M. caliginosa P. James & D. Galloway
M. confusa **P. James**
M. eperforata P. James & D. Galloway
M. globulifera R. Sant.
M. inactiva **P. James & Kantvilas**
M. minuta **P. James & Kantvilas**
M. nothofagi (Zahlbr.) P. James & D. Galloway
M. platytrema (Müll. Arg.) R. Sant.
M. retipora **(Stirton) Bitter**
M. subbullata **P. James & Kantvilas**
M. subpertusa P. James & D. Galloway
M. testacea P. James & D. Galloway
M ultralucens P. James & D. Galloway
M. weindorferi **(Zahlbr.) R. Sant.**

Metus conglomeratus (F. Wilson) D. Galloway & P. James

Micarea prasina Fr.
M. prasinella **(Jatta) M. Lamb**

Microcalicium arenarium (Hampe ex Massal.) Tibell
M. conversum Tibell

Microthelia analtiza (Stirton) Zahlbr. (+)

Miltidea ceroplasta (Church. Bab.) D. Galloway & Hafellner

Multiclavula mucida (Pers.) R.H. Petersen
M. vernalis (Schw.) R.H. Petersen

Mycocalicium albonigrum (Nyl.) Tibell
M. subtile (Pers.) Szat.
M. victoriae (C. Knight ex F. Wilson) Tibell

Mycoporellum obscurum (Pers.) A.L. Smith (+)

[*Neofuscelia glabrans* (Nyl.) Esslinger]
N. imitatrix (Taylor) Esslinger
N. loxodella **(Esslinger) Esslinger**
N. pulla (Ach.) Esslinger
N. stygioides (Nyl. ex Crombie) Esslinger
N. verrucella (Esslinger) Esslinger

Neophyllis melacarpa (F. Wilson) F. Wilson

Nephroma australe Richard
N. cellulosum (Ach.) Ach. var. *cellulosum*
N. rufum (Church. Bab.) P. James

Normandina pulchella (Borrer) Nyl.

Ochrolechia frigida (Sw.) Lynge
O. pallescens (L.) Massal. (+)
O. parella (L.) Massal. (+)
O. weymouthii **Jatta**

Opegrapha agelaeina **Jatta**
O. stellata Knight

Pannaria fulvescens (Mont.) Nyl.
P. immixta Nyl.
P. mariana (Fr.) Müll. Arg. (+)
P. pezizoides (Web.) Trevis.
P. rubiginosa (Thunb. ex Ach.) Delise (+)

Pannoparmelia angustata (Pers. in Gaud.) Zahlbr.
P. wilsonii (Räsänen) D. Galloway

Paraparmelia conranensis (Elix) Elix & Johnston
P. lithophiloides (Kurok.) Elix & Johnston
[*P. mongaensis* (Elix) Elix & Johnston]

Parmelia cunninghamii Crombie
P. erumpens Kurok.
P. protosulcata Hale
P. pseudorelicina **Jatta** (type not located; unlikely to belong to *Parmelia s. strict.*)
P. salcrambidiocarpa Hale
P. signifera Nyl.
P. sulcata Taylor
P. tenuirima **J.D. Hook. & Taylor**
P. testacea Stirton

Parmeliella microphylla (Sw.) Müll. Arg. (+)
P. nigrocincta (Mont.) Müll. Arg.
P. rubiginascens (Nyl.) Müll. Arg. (+)
[*P. subgranulata* D. Galloway & P.M. Jørg.]

Parmelina labrosa (Zahlbr.) Elix & Johnston
P. stevensiana Elix & Johnston

Parmelinopsis afrorevoluta (Krog & Swinsc.) Elix & Hale
P. horrescens (Taylor) Elix & Hale (+)
P. spumosa (Asahina) Elix & Hale (+)
P. subfatiscens (Kurokawa) Elix & Hale

Parmentaria gregalis (Knight) Müll. Arg. (+)

Parmotrema chinense (Osbeck) Hale & Ahti
[*P. cristiferum* (Taylor) Hale]
P. reticulatum (Taylor) Choisy
P. subcaperatum (Krempelh.) Hale (+)

Peltigera canina (L.) Willd. (+)
P. canina f. *leucorrhiza* (Flörke) Flörke (+)
***P. degenii* Gyelnik f. *tasmaniae* Gyelnik**
P. didactyla (With.) Laundon
P. dolichorhiza (Nyl.) Nyl.
P. horizontalis (Huds.) Baumg. (+)
P. membranacea (Ach.) Nyl. (+)
P. polydactyla (Neck.) Hoffm. (+)
P. pusilla (Fr.) Körber (+)
P. rufescens (Weis) Humb. (+)

Peltula euploca (Ach.) Poelt ex Ozenda & Clauz.

Pertusaria aggregata Müll. Arg. (+)
P. alpina Hepp ex Ahles
P. commutata Müll. Arg. (+)
***P. gibberosa* Müll. Arg.**
P. lacerans Müll. Arg. (+)
P. leucostoma (Bernh.) Mass. (+)
P. meridionalis Müll. Arg. var. *xanthostoma* Müll. Arg. (+)
P. novaezelandiae Szat.
P. ornatula Müll. Arg. (+)
P paratropa Müll. Arg. (+)
***P. pertractata* Stirton**
P. superba Zahlbr.
P. truncata Krempelh.
P. trypheliformis (Nyl.) (+)

Phaeographis australiensis Müll. Arg.
P. exaltata (Mont. & v.d. Bosch) Müll. Arg.

Phaeophyscia endocoecinoides (Poelt) Esslinger
P. orbicularis (Neck.) Moberg

Phlyctis subuncinata Stirton

Phyllopsora congregans (Zahlbr.) D. Galloway
P. parvifolia (Pers.) Müll. Arg. (+)

Physcia adscendens (Fr.) Oliver
P. aipolia (Ehrh. ex Humb.) Fürnr. (+)
[*P. alba* (Fée) Müll. Arg. (+)]
P. albata (F. Wilson) Hale (+)
[*P. albicans* (Pers.) Thomson (+)]
P caesia (Hoffm.) Fürnr.
P. clementei (Sm.) Lynge
P. stellaris (L.) Lynge
[*P. tribacia* (Ach.) Nyl. (+)]

Physconia grisea (Lam.) Poelt (+)

Physma chilense Hue

Placopsis cribellans (Nyl.) Räsänen
P. gelida (L.) Lindsay
P. parellina (Nyl.) Lamb
P. parellina f. *microphylla* Lamb
P. perrugosa (Nyl.) Nyl.
P. rhodocarpa (Nyl.) Wetmore
P. trachyderma (Krempelh.) P. James var. *clavifera* (Lamb) P. James

Placynthium nigrum (Huds.) S.F. Gray

Porina leptaleina (Nyl.) Müll. Arg.

Protoblastenia rupestris (Scop.) J. Steiner

Protoparmelia badia (Hoffm.) Hafellner (+)
***P. petraeoides* (Nyl. ex Hue) Hertel**

Pseudephebe pubescens (L.) Choisy

Pseudocyphellaria ardesiaca D. Galloway
P. argyracea (Delise) Vainio
P. aurata (Sm.) Vainio
P. billardierei (Delise) Räsänen
P. colensoi (Church. Bab.) Vainio
P. coronata (Müll. Arg.) Malme
P. crocata (L.) Vainio
P. dissimilis (Nyl.) D. Galloway & P. James
P. faveolata (Delise) Malme
P. glabra (J.D. Hook. & Taylor) Dodge
P. granulata (Church. Bab.) Malme
P. insculpta (Stizenb.) D. Galloway
P. intricata (Delise) Vainio
P. multifida (Nyl.) D. Galloway & P. James
P. neglecta (Müll. Arg.) Vainio
***P. rubella* (J.D. Hook. & Taylor) D. Galloway & P. James**

Psilolechia clavulifera (Nyl.) Coppins
P. lucida (Ach.) Choisy
***P. purpurascens* Coppins & Purvis**

Psora decipiens (Hedw.) Hoffm. (+)

Psoroma allorhizum (Nyl.) Hue (+)
P. asperellum Nyl.
P. durietzii P. James & Henssen
P. euphyllum Nyl.
P. hirsutulum Nyl. ex Crombie (+)
P. hypnorum (Vahl) S.F. Gray
P. leprolomum (Nyl.) Räsänen
P. microphyllizans (Nyl.) D. Galloway

P. paleaceum (Fr.) Nyl.
P. pallidum Nyl. (+)
P. pholidotoides (Nyl.) Trevis.
P. pholidotum (Mont.) Müll. Arg. (+)
***P. soccatum* R.Br.**
P. sphinctrinum (Mont.) Nyl. (+)
P. xanthomelanum Nyl. (+)

Psoromidium aleuroides (Stirton) D. Galloway
P. versicolor (J.D. Hook. & Taylor) D. Galloway

Punctelia borreri (Sm.) Krog
***P. subflava* (Taylor) Elix & Johnston**
P. subrudecta (Nyl.) Krog

Pycnothelia caliginosa D. Galloway & P. James

***Pyrenopsis tasmanica* Nyl.**

***Pyrenula chloroplaca* Shirley**
***P. galactina* (Shirley) Kantvilas**
P. kunthii (Fée) Fée (+)

Pyrgillocarpon indicum (Krempelh.) Nádv. in Tibell

Pyxine nubila Moberg

Ramalea cochleata Müll. Arg.

Ramalina caespitella N. Stevens
[*R. canariensis* Steiner]
R. celastri (Sprengel) Krog & Swinsc. ssp. *celastri*
***R. celastri* ssp. *ovalis* (J.D. Hook. & Taylor) N. Stevens**
R. fimbriata Krog & Swinsc.
R. fissa (Müll. Arg.) Vainio
R. glaucescens Krempelh.
R. inflata (J.D. Hook. & Taylor) J.D. Hook. & Taylor ssp. *inflata*
R. inflata ssp. *australis* N. Stevens
R. unilateralis F. Wilson
***R. whinrayi* N. Stevens**

Ramalodium succulentum Nyl.

Relicina limbata (Laurer) Hale
R. subnigra Elix & Johnson

Rhizocarpon badioatrum (Flörke ex Sprengel) Th.Fr. f. *atroalbum* (L.) Malme (+)
R. geographicum (L.) DC.
R. petraeum (Wulfen) Massal. (+)

***Rinodina asperata* (Shirley) Kantvilas**
R. bischoffii (Hepp) Massal.
***R. brattii* Mayrhofer**
R. conradii Körber
***R. dissa* (Stirton) Mayrhofer**
R. exigua (Ach.) S.F. Gray (+)
R. gennarii Bagl.
R. murrayi Mayrhofer
R. occulta (Körber) Sheard
R. peloleuca (Nyl.) Müll. Arg.
R. procellarum (Massal.) Mayrhofer
R. subcrustacea (Müll. Arg.) Zahlbr.
***R. tasmanica* Mayrhofer**
R. thiomela (Nyl.) Müll. Arg.

[*Roccellina expectata* Tehler]

Roccellinastrum neglectum Henssen &Vobis

Sagenidium molle Stirton

***Sarrameana tasmanica* Vezda & Kantvilas**

***Schismatomma congerens* (Nyl.) Zahlbr.**

Scoliciosporum pruinosum (P. James) Vezda

Siphula complanata (J.D. Hook. & Taylor) R. Sant.
S. decumbens Nyl.
***S. foliacea* D. Galloway**
***S. fragilis* (J.D. Hook. & Taylor) J.Murray**
***S. jamesii* Kantvilas**

Siphulastrum mamillatum (J.D. Hook. & Taylor) D. Galloway
S. triste Müll. Arg.

Sphaerophorus imshaugii Ohlsson in D. Galloway
S. insignis Laurer
S. macrocarpus Ohlsson in D. Galloway
S. melanocarpus (Sw.) DC.
S. murrayi Ohlsson in Tibell
S. notatus Tibell
S. patagonicus (Dodge) Ohlsson in D. Galloway
S. ramulifer Lamb
S. scrobiculatus (Church. Bab.) Sato
S. tener Laurer

Sphinctrina leucopoda Nyl.
S. tubaeformis Massal.

Stephanocyclos henssenianus Hertel

Stereocaulon caespitosum Redinger
S. corticatulum Nyl. var. *corticulatum*
S. corticatulum var. *humile* (Müll. Arg.) Lamb
S. corticatulum var. *subcorticatum* (Räsänen) Lamb
S. gregarium Redinger
S. ramulosum (Sw.) Räuschel
***S. trachyphloeum* Lamb**
S. vesuvianum Pers.

Sticta damaecornis (Sw.) Ach. (+)
S. fuliginosa (Dickson) Ach.
S. limbata (Sm.) Ach.
S. macrophylla Delise (+)
S. querzicans Delise (+)
S. stipitata Knight
S. subcaperata (Nyl.) Nyl. (+)
S. sublimbata (Steiner) Swinsc. & Krog

S. sylvatica (Huds.) Ach. (+)
S. weigelii (Ach.) Vainio (+)

Synalissa cancellata F. Wilson (+)

Teloschistes chrysophthalmus (L.) Th. Fr.
T. flavicans (Sw.) Norm.
T. sieberianus (Laurer) Hillm.
***T. spinosus* (J.D. Hook. & Taylor) J. Murray**
T. spinosus f. *subteres* R. Filson
T. velifer F. Wilson
[*T. velifer* f. *nodulosa* (J. Murray) R. Filson]

Tephromela atra (Huds.) Hafellner

Thamnolia vermicularis (Sw.) Ach. ex Schaerer var. *vermicularis*
T. vermicularis var. *subuliformis* (Ehrh.) Schaerer

Thelotrema decorticans Müll. Arg.
T. lepadinum (Ach.) Ach.
T. subdenticulatum (Zahlbr.) G. Salisb.
T. subgranulosum Jatta

Thysanothecium hookeri Mont. & Berk.
T. scutellatum (Fr.) D. Galloway

Toninia bullata (Meyen & Flotow) Zahlbr.
T. microlepis (Müll. Arg.) Zahlbr. (+)

Trapelia coarctata (Turner) Choisy (+)

Trapeliopsis colensoi (Church. Bab.) G. Schneider
T. granulosa (Hoffm.) H.T. Lumbsh

Tremolecia atrata (Ach.) Hertel

Turgidosculum complicatulum (Nyl.) J. Kohlmeyer & E. Kohlmeyer

Umbilicaria cylindrica (L.) Delise ex Duby
U. hyperborea (Ach.) Hoffm.
U. polyphylla (L.) Baumg.
U. propagulifera (Vainio) Llano
U. subglabra (Nyl.) Harm.

Usnea acromelana Stirton
U. angulata Ach. (+)
U. baileyi (Stirton) Zahlbr.
U. capillacea Motyka
U. ceratina Ach. (+)
U. contexta Motyka
U. hirta (Müll. Arg.) Weber em. Motyka (+)
U. inermis Motyka
U. leprosa Motyka
U. maculata Stirton
U. molliuscula Stirton
U. ramulosissima Stevens & Rogers
U. rubicunda Stirton
U. scabrida Taylor
U. spilota Stirton (+)
U. subcapillaris (D. Galloway) F.J. Walker
U. torquescens Stirton
U. torulosa (Müll. Arg.) Zahlbr.
U. trichodea Ach. (+)
U. xanthopoga Nyl. (+)

Verrucaria maura Wahlenb. ex Ach.
V. microsporoides Nyl.

Vezdaea obscura Döbbeler

Wawea fruticulosa Henssen & Kantvilas

Xanthoparmelia adhaerens (Nyl.) Hale
X. alexandrensis Elix & Johnston
X. amphixantha (Müll. Arg.) Hale
X. amplexula (Stirton) Elix & Johnston
X. antleriformis (Elix) Elix & Johnston
X. arapilensis (Elix & P. Armstr.) Filson
X. australasica D. Galloway
X. bungendorensis (Elix) Elix & Johnston
X. cheelii (Gyelnik) Hale
X. congesta (Kurok. & Filson) Elix & Johnston
X. constrictans (Nyl. ex Crombie) Hale
X. cordillerana (Gyelnik) Hale
X. dichotoma (Müll. Arg.) Hale
X. digitiformis (Elix & P. Armstr.) Filson
X. dissitifolia Kurok. ex Elix & Johnston
X. elixii Filson
X. filarszkyana (Gyelnik) Hale
X. flaviscentireagens (Gyelnik) D. Galloway
X. furcata (Müll. Arg.) Hale
X. glareosa (Kurok. & Filson) Elix & Johnston
X. hybridiza Elix & Johnston
[*X. incerta* (Kurok. & Filson) Elix & Johnston]
X. isidiigera (Müll. Arg.) Elix & Johnston
X. isidiosa (Müll. Arg.) Elix & Johnston
[*X. lineola* (Berry) Hale]
X. mannumensis (Elix) Elix & Johnston
X. metaclystoides (Kurok. & Filson) Elix & Johnston
X. mexicana (Gyelnik) Hale
X. mougeotina (Nyl.) D. Galloway
X. multipartita (R. Br.) Hale
X. neotinctina (Elix) Elix & Johnston
X. notata (Kurok.) Hale
X. phillipsiana (Filson) Elix & Johnston
X. pseudohypoleia (Elix) Elix & Johnston
X. pustuliza (Elix) Elix & Johnston
[*X. remanens* (Elix) Elix & Johnston]
X. scabrosa (Taylor) Hale
X. streimannii (Elix & P. Armstr.) Elix & Johnston
X. subnuda (Kurok.) Hale
X. substrigosa (Hale) Hale
X. taractica (Kremp.) Hale
***X. tasmanica* (J.D. Hook. & Taylor) Hale**
X. tegeta Elix & Johnston
X. thamnoides (Kurok.) Hale
X. verdonii Elix & Johnston
***X. vicaria* Elix & Johnston**
X. willisii (Kurok. & Filson) Elix & Johnston

Xanthoria ligulata (Körber) P. James
X. parietina (L.) Th. Fr.

DELETED NAMES

Acarospora schleicheri (Ach.) Massal. Probably refers to *A. citrina* (Tayl.) Zahlbr. ex Rech. (Lumbsch 1988b)

Alectoria lanata (Neck.) Nyl. ≡ *Pseudephebe pubescens* (L.) Choisy

Alectoria pubescens (L.) Howe ≡ *Pseudephebe pubescens* (L.) Choisy

Anaptychia spp. All Tasmanian records of this genus refer to species of *Heterodermia*.

Anzia angustata (Pers. in Gaud.) Müll. Arg. ≡ *Pannoparmelia angustata* (Pers. in Gaud.) Zahlbr.

Anzia colpodes (Ach.) Stizenb. Misapplied to *Pannoparmelia angustata* (Pers. in Gaud.) Zahlbr.

Anzia wilsonii Räsänen ≡ *Pannoparmelia wilsonii* (Räsänen) D. Galloway

***Arthonia multiformis* Shirley** ≡ *Arthothelium ilicinum* (Taylor) P. James

***Arthothelium ferax* (Müll. Arg.)** ≡ *A. interveniens* (Nyl.) Zahlbr.

Arthothelium infuscatum (Krempelh.) Müll. Arg. ≡ *A. interveniens* (Nyl.) Zahlbr.

Aspicilia alpina (Sommerf.) Arnold ≡ *Bellemerea alpina* (Sommerf.) Clauz. & Roux

Baeomyces fungoides (Sw.) Ach. Refers to *B. arcuatus* Stirton in Australasia (see Kantvilas & James 1987).

Baeomyces ramalinellus Nyl. Misapplied to *B. arcuatus* Stirton.

Baeomyces roseus Pers. Not present in Tasmania; most likely misapplied to *B. arcuatus* Stirton.

***Baeomyces squamarioides* Nyl.** ≡ *Knightiella splachnirima* (J.D. Hook. & Taylor) Gyelnik

Blastenia consanguinea Müll. Arg. Misidentification of *Megaloblastenia marginiflexa*. (J.D. Hook. & Taylor) Sipman (Kantvilas 1988).

Blastenia endochromoides Müll. Arg. ≡ *Megaloblastenia marginiflexa* (J.D. Hook. & Taylor) Sipman

Bombyliospora tuberculosa (Fée) Massal. (≡ *Megalospora tuberculosa* (Fée) Sipman). Not present in Tasmania (Sipman 1983).

Buellia dissa Stirton ≡ *Rinodina dissa* (Stirton) Mayrhofer

Buellia parasema (Ach.) De Not. ≡ *B. disciformis* (Fr.) Mudd

***Buellia polospora* (Leighton) Shirley var. *asperata* Shirley** ≡ *Rinodina asperata* (Shirley) Kantvilas

Buellia pulchella (Schrad.) Tuck. ≡ *Catolechia wahlenbergii* (Ach.) Körber. Not present in Australia or Tasmania (R.W. Rogers, pers. comm.)

Calicium lenticulare (Hoffm.) Ach. Not present in Tasmania (Tibell 1987).

Calicium piperatum F.Wilson ≡ *C. victorianum* ssp. *victorianum* (F. Wilson) Tibell

Calicium quercinum Pers. var. *microcarpum* F.Wilson ≡ *C. glaucellum* Ach.

Calicium robustellum Nyl. Not recorded for Tasmania by Tibell (1987).

Calicium roscidulum Nyl. ex F. Wilson ≡ *C. trabinellum* (Ach.) Ach.

Calicium roseo-albidum F. Wilson ≡ *C. salicinum* Pers.

Calicium victoriae F. Wilson ≡ *Mycocalicium victoriae* (F. Wilson) Tibell

Caloplaca aurantiaca (Lightf.) Th. Fr. ≡ *C. flavorubescens* (Huds.) Laundon

Canoparmelia norsticticata (Stevens) Elix & Hale. Not recorded for Tasmania by Elix & Stevens (1979).

Carbonea phaeostoma (Nyl.) Hertel. Not recorded for Tasmania by Hertel (1984).

Catillaria melanotropa (Nyl.) Zahlbr. The specimen upon which this record is based (Shirley 1894) is *C. tasmanica* Räsänen (see Kantvilas 1988).

Catinaria versicolor (Fée) Sipman. Although listed for Tasmania by Filson (1988b), this name appears to have been widely misapplied by early workers to several species of *Megalospora* or *Catinaria*.

Catolechia wahlenbergii (Ach.) Körber. Not present in Australia (R. Rogers, pers. comm.).

Cetraria scutata (Wulf.) Poetsch ≡ *C. chlorophylla* (Willd.) Vainio

Chiodecton perplexum Nyl. The specimen upon which the Tasmania record is based (Shirley 1894) is of *C. colensoi* (Massal.) Müll. Arg. (see Kantvilas 1988).

Cladina alpestris (L.) Nyl. Not present in Tasmania (Ahti 1984).

Cladina leptoclada (des Abb.) D. Galloway ≡ *C. confusa* (R. Sant.) Follm. & Ahti

Cladina rangiferina (L.) Nyl. Not present in Tasmania (Ahti 1984).

Cladina sylvatica (Hofm.) Leighton. Not present in Tasmania (Ahti 1984).

Cladonia acuminata (Ach.) Norrl. Not recorded for Australia by Archer (in prep.).

Cladonia aggregata (Sw.) Sprengel ≡ *Cladia aggregata* (Sw.) Nyl.

Cladonia aggregata f. *subdivergens* Hellbom ≡ *Cladia aggregata* (Sw.) Nyl.

Cladonia aggregata var. *tenera* F. Wilson ≡ *Cladia aggregata* (Sw.) Nyl.

Cladonia amaurocraea (Florke) Schaerer. An arctic and subarctic Northern Hemisphere species, not recorded for Australia by Archer (in prep.).

Cladonia anomaea (Ach.) Ahti & P. James ≡ *C. ramulosa* (With.) Laundon

Cladonia bacillaris (Ach.) Nyl. Included in *C. macilenta* Hoffm. (Christensen 1987) and not recorded for Tasmania by Archer (in prep.)

Cladonia borbonica (Delise) Nyl. Not recorded for Australia by Archer (in prep.).

Cladonia calycantha Delise ex Nyl. Not present in Tasmania. Probably refers to *C. cervicornis* ssp. *verticillata* (Hoffm.) Ahti (see Ahti 1983).

Cladonia campbelliana (Vainio)Gyelnik ≡ *C. sarmentosa* (J.D. Hook. & Taylor) Dodge

Cladonia capitata (Michaux) Sprengel. Refers to *C. tessellata* Ahti & Kashiwadani in Tasmania.

Cladonia carassensis Vainio. This species is presently considered to be a thamnolic acid-containing form of *C. crispata* (Ach.) Flotow (Stenroos 1988).

Cladonia cariosa (Ach.) Sprengel. Refers to *C. tessellata* Ahti & Kashiwadani in Tasmania.
Cladonia carneopallida (Flörke) Laurer. Not recorded for Australia by Archer (in prep.).
Cladonia cenotea (Ach.) Schaerer. Not recorded for Australia by Archer (in prep.).
Cladonia ceratophylla (Sw.) Sprengel. Refers to *C. praetermissa* Archer (Filson 1986).
Cladonia coccifera. (L.) Willd. Not present in Tasmania (Archer 1988a).
Cladonia coniocraea auct. Does not appear to occur in Tasmania (Archer, pers. comm.).
Cladonia conoidea Ahti ≡ C.humilis (With.) Laundon.
Cladonia conista auct. ≡ *C. humilis* var. *bourgeanica* (Archer 1988b).
Cladonia cornicularia Laurer ≡ *Cladia aggregata* (Sw.) Nyl.
Cladonia decorticata (Flörke) Sprengel. Not recorded for Australia by Archer (in prep.)
***Cladonia decurva* Taylor ex Church. Bab. & Mitten** ≡ *C. scabriuscula* (Delise) Nyl. (Archer, pers. comm.).
Cladonia deformis (L.) Hoffm. All records of this species from Tasmania appear to refer to *C. pleurota* (Flörke) Schaerer.
Cladonia digitata (L.) Hoffm. Not recorded for Australia (Archer 1988a).
Cladonia enantia Nyl. Not present in Tasmania. All records probably refer to *C. tessellata* Ahti & Kashiwadani.
Cladonia farinacea (Vainio) Evans. Not recorded for Australia by Archer (in prep.).
Cladonia firma (Laurer) Krempelh. ≡ *C. murrayi* Martin.
Cladonia foliacea (Huds.) Willd. Not recorded for Australia by Archer (in prep.).
Cladonia gorgonina. (Bory) Vainio ≡ *Cladia aggregata* (Sw.) Nyl.
Cladonia impexa Harm. [≡ *Cladina portentosa* (Duf.) Follm.]. Not present in Tasmania.
Cladonia macilenta Hoffm. Not present in Tasmania.
Cladonia neozelandica Vainio. Not present in Tasmania.
Cladonia parasitica (Hoffm.) Hoffm. Not recorded for Australia by Archer (in prep.).
Cladonia phyllophora Hoffm. Not recorded for Australia by Archer (in prep.).
Cladonia pityrea (Flörke) Fr. ≡ C. *ramulosa* (With.) Laundon.
Cladonia polydactyla (Flörke) Nyl. Not recorded for Australia by Archer (in prep.).
Cladonia portentosa (Duf.) Coem. Not present in Tasmania and referrable to *Cladina*.
Cladonia rangiformis Hoffm. Not present in Tasmania.
Cladonia rappii var. *exilior* (des. Abb.) Ahti ≡ *C. cervicornis* ssp. *verticillata* (Hoffm.) Ahti.
Cladonia rei Schaerer. Not present in Tasmania. Record cited by Kantvilas & Jarman (1988) refers to material of *C. ramulosa* (With.) Laundon containing homosekikaic acid.
Cladonia sparassa (Ach.) Hampe. ≡ *C. squamosa* (Scop.) Hoffm. Not recorded for Australia by Archer (in prep.).
Cladonia squamosa (Scop.) Hoffm. Not recorded for Australia by Archer (in prep.).
Cladonia squamosula Müll. Arg. var. *squamosula* ≡ *C. rigida* var. *rigida* (J.D. Hook. & Taylor) Hampe.
Cladonia squamosula var. *subsquamosula* Archer ≡ *C. rigida* var. *acuta* (Taylor) Archer.
Cladonia subcervicornis (Vainio) Kernst. Not recorded for Australia by Archer (in prep.).
Cladonia subsquamosa (Nyl.) Vainio. Not present in Tasmania (Archer, in prep.).
Cladonia subsubulata Nyl. This species is presently considered to be a thamnolic-acid-containing form of *C. crispata* (Ach.) Flowtow (Stenroos 1988).
Cladonia subulata (L.) Wigg. Refers to *C. corniculata* Ahti & Kashiwadani in Tasmania.
Cladonia terebrata (Laurer) Flörke ≡ *Cladia aggregata* (Sw.) Nyl.
Cladonia uncialis (L.) Wigg. Not present in Tasmania. Probably a misidentification of *C. capitellata* (J.D. Hook. & Taylor) Church. Bab.
Cladonia verticillata (Hoffm.) Schaerer ≡ *C. cervicornis* ssp. *verticillata* (Hoffm.) Ahti
Cladonia wilsonii Archer ≡ C. *sulcata* var. *wilsonii* (Archer) Archer
Coccocarpia cronia (Tuck.) Vainio ≡ *C. palmicola* (Spreng.) Arvidsson & D. Galloway
Coccocarpia gayana (Mont.) Nyl. ≡ *Degelia gayana* (Mont.) Arvidsson & D. Galloway
Coccocarpia parmelioides (Hook.) Tuck ≡ *C. erythroxli* (Spreng.) Swinsc. & Krog.
Coenogonium acrocephalum Müll. Arg. Misidentification of *C. implexum* Nyl. (see Kantvilas 1988).
Coenogonium linkii Ehrh. Not in Tasmania and probably misapplied to *C. implexum* Nyl.
Coenogonium rigidulum Müll. Arg. Not in Tasmania and probably misapplied to *C. implexum* Nyl.
Collema nigrescens (Huds.) DC. Misapplied to *C.glaucophthalmum* Nyl. (Degelius 1974).
Collema robillardii (Müll. Arg.) Stizenb. Misapplied to *C. quadriloculare* F. Wilson (Degelius 1974).
Collema thysaneum Ach. Not in Tasmania and probably misapplied to both *C. leucocarpum* J.D. Hook. & Taylor and *C. fasciculare* (L.) Wigg. (Degelius 1974).
Cornicularia aculeata (Schreber) Ach. ≡ *Coelocaulon aculeatum* (Schreber) Link.
Crocynia mollescens Nyl. Most probably refers to a species of *Lepraria*.
Cyphelium emergens (F. Wilson) Zahlbr. ≡ *Trachylia emergens* F. Wilson. This species represents a non-lichenised fungus (Tibell 1987).
Cystocoleus ebeneus (Dillwyn) Thwaites ≡ *C. niger* (Hudson) Hariot
Delisea pseudosticta Fée ≡ *Pseudocyphellaria glabra* (J.D. Hook. & Taylor) Dodge.
Dermatocarpon hepaticum (Lam.) Th.Fr. ≡ *Catapyrenium lachneum* (Ach.) R. Sant.
Diploschistes euganeus (Massal.) Steiner. Not present in Tasmania (H.T. Lumbsch, pers. comm.).
***Diploschistes subocellatus* (Nyl.) Zahlbr.** ≡ *D. ocellatus* (Vill.) Norm. (H.T. Lumbsch, pers. comm.).
Dufourea collodes J.D. Hook. & Taylor ≡ *Cladia aggregata* (Sw.) Nyl.

Ephebe pubescens Fr. Wilson's (1893) record of this taxon refers to *Pseudephebe pubescens* (L.) Choisy.

Ephebe tasmanica Crombie. Known only from the type collection (Grosse River, N.S.W.). This locality is frequently quoted as being in Tasmania due to an error by Crombie (1880).

Flavoparmelia ferax (Müll. Arg.) Hale. Not known from Tasmania or the Bass Strait islands (J. Elix, pers. comm.).

Gomphillus baeomyceoides Wilson ≡ *Bacidia buchananii* (Stirton) Hellbom

Graphis intricata Fée. Incorrectly listed for Tasmania by Shirley (1893) on the basis of a collection by Robert Brown at Grosse River, N.S.W. (see Crombie 1880).

Gyalecta cupularis (Hedwig) Schaerer ≡ *G. jenensis* (Batsch) Zahlbr.

Gymnoderma melacarpum (F. Wilson) Yoshim. ≡ *Neophyllis melacarpa* (F. Wilson) F. Wilson.

Heterodermia pseudospeciosa (Kurok.) Culb. Erroneously reported by Kantvilas *et al.* (1985) on the basis of a misidentification of *H. microphylla* (Kurok.) Swinsc. & Krog (see Kantvilas & James 1987).

Heterodermia tremulans (Müll. Arg.) Culb. ≡ H. speciosa (Wulf.) Trevis.

***Heterothecium pauciseptatum* Shirley** ≡ *Austroblastenia pauciseptata* (Shirley) Sipman

Hypogymnia encausta (Sm.) W. Watson. Refers to *H. tubularis* (Taylor) Elix (Filson 1986).

Hypogymnia enteromorpha (Ach.) Nyl. Refers to *H. enteromorphoides* Elix (Filson 1986) in Australia.

Hypogymnia physodes (L.) Nyl. Widely misapplied to several species of *Hypogymnia* in Tasmania, especially to *H. subphysodes* (Krempelh.) Filson.

Hypogymnia vittata (Ach.) Gasilien. Not present in Tasmania (Elix 1979).

Lecanora angulosa (Schreber) Ach. ≡ *L. carpinea* (L.) Vainio

Lecanora atra (Huds.) Ach. ≡ *Tephromela atra* (Huds.) Hafellner

Lecanora badia (Hoffm.) Ach. ≡ *Protoparmelia badia* (Hoffm.) Hafellner

Lecanora coarctata (Sm.) Ach. ≡ *Trapelia coarctata* (Sm.) Choisy

Lecanora glaucoma (Hoffm.) Ach. ≡ *L. rupicola* (L.) Zahlbr.

Lecanora parmelina Zahlbr. ≡ *L. broccha* Nyl.

Lecanora sordida (Pers.) Th.Fr. ≡ *L. rupicola* (L.) Zahlbr.

Lecanora sulphurea (Hoffm.) Ach. Origin of record doubtful and no Tasmanian specimens identified as this species have been seen.

Lecidea cinnabarina Sommerf. Refers to *L. laeta* Stirton.

Lecidea crystallifera Taylor ≡ *Eremastrella crystallifera* (Taylor) G. Schneider

Lecidea decipiens (Hedw.) Ach. ≡ *Psora decipiens* (Hedw.) Hoffm.

Lecidea dicksonii auct. ≡ *Tremolecia atrata* (Ach.) Hertel

Lecidea friesii Ach. [≡ *Hypocenomyce friesii* (Ach.) P. James & G. Schneider]. Not present in Tasmania.

Lecidea interversa Nyl. ≡ *L. canorufescens* Krempelh.

Lecidea ostreata (Hoffm.) Schaerer. Refers to a species of *Hypocenomyce*.

***Lecidea petraeoides* Nyl. ex Hue** ≡ *Protoparmelia petraeoides* (Nyl. ex Hue) Hertel

Lecidea russula Ach. Refers to *L. laeta* Stirton in Tasmania.

Lepraria candelaris (L.) Fr. ≡ *Chrysothrix candelaris* (L.) Laundon

Leptogium azureum (Sw.) Mont. in Webb & Berthelot. Not in Tasmania. Most material given this name in Australia is *Collema subconveniens* Nyl. (D. Verdon, pers. comm.).

Leptogium brebissonii Mont. in Webb & Berthelot. Not in Tasmania. Easily confused with small *Collema* spp. (D. Verdon, pers. comm.).

Leptogium chloromelum var. *granulare* Müll. Arg. The specimen upon which this record is based (Shirley 1894) is referrable to *Psoroma hypnorum* (Vahl.) S.F. Gray (Kantvilas 1988).

Leptogium rugosum Sierk. Not present in Tasmania.

Leptogium scotinum (Ach.) Fr. Not present in Tasmania.

Leptogium tenuissimum (Dickson) Fr. The sole Tasmanian record of this species is attributed to Hampe (1852) by Wetmore (1963), but the original reference is to *Parmelia tenuissima* (≡ *P. signifera*) and not to a *Leptogium*.

Leptogium tremelloides (Linn. f.) S.F. Gray. Widely used name in early literature, apparently misapplied to *L. azureum* (Sw.) Mont. and *L. cyanescens* (Ach.) Körber.

Letrouitia domingensis (Pers.) Hafellner & Bellemère. A tropical species not recorded for Tasmania by Hafellner (1981).

Lichina pygmaea (Lightf.) Agardh var. *intermedia* Church. Bab. ≡ *L. confinis* (O.F. Mull.) Agardh

Lobaria crenulata (J.D. Hook.) Trevis. This record is based on "a single specimen of poor quality" (Babington & Mitten 1859) collected by R.C. Gunn. The specimen is cited in the catalogues of Müller (1887), Shirley (1893) and Wilson (1893), each time as a different *Lobaria* species, and thus has led to the introduction of several *Lobaria* names into Tasmanian (and Australian) checklists. Given the dubiousness of the original identification, and the lack of more recent gatherings, *L. crenulata* and the other species names associated with Gunn's specimen (see below) are deleted.

Lobaria herbacea (Huds.) DC. See under *L. crenulata* (above).

Lobaria laetevirens (Lightf.) Zahlbr. See under *L. crenulata* (above).

Lobaria leucocarpa (Müll. Arg.) Zahlbr. ≡ *Knightiella splachnirima* (J.D. Hook. & Taylor) Gyelnik

Lobaria patinifera (Taylor) Hue. See under *L. crenulata* (above).

Lobaria sublaevis Nyl. See under *L. crenulata* (above).

Lopadium pauciseptatum (Shirley) Zahlbr. ≡ *Austroblastenia pauciseptata* (Shirley) Sipman

Mastodia tessellata auct. ≡ *Turgidosculum complicatulum* (Nyl.) J. Kohlmeyer & E. Kohlmeyer

Megalospora coccodes (Bel.) Sipman. Not recorded for Tasmania by Sipman (1983).

Megalospora sulphurata var. *nigricans* (Müll. Arg.) Riddle. Not present in Tasmania (Sipman 1983).

***Megalospora tasmanica* (Jatta) Zahlbr.** Sipman (1983) observed that the type specimen has acicular spores and is therefore not a *Megalospora*.

***Megalospora taylori* Dodge.** Not accepted by Sipman (1983).

Menegazzia diatrypa (Ach.) Massal. [≡ *M. terebrata* (Hoffm.) Massal.]. Not present in Tasmania.

***Menegazzia myriotrema* (Müll. Arg.) R. Sant.** ≡ *M. platytrema* (Müll. Arg.) R. Sant. (P. James, pers. comm.).

Menegazzia pertransita (Stirton) R. Sant. Refers to *M. weindorferi* (Zahlbr.) R. Sant. in Tasmania.

Menegazzia pertusa (Schrank) B. Stein [≡ *M. terebrata* (Hoffm.) Massal.] Not present in Tasmania.

Nephroma antarcticum (Wulf.) Nyl. Refers to *N. australe* A. Rich.

Nephroma helveticum Ach. Not present in Tasmania (White & James 1988).

Nephroma lepidophyllum Räsänen ex Gyelnik ≡ *N. cellulosum* var. *isidioferum* J. Murray. Not present in Tasmania (White & James 1988).

Nephroma resupinatum (L.) Ach. f. *papyraceum* (Hoffm.) Ach. ≡ *N. helveticum* Ach. Not present in Tasmania.

Neuropogon acromelanus var. *decipiens* Lamb ≡ *Usnea acromelana* Stirton.

Neuropogon acromelanus var. *inactivus* Lamb ≡ *Usnea torulosa* (Müll. Arg.) Zahlbr.

Neuropogon antarcticus (Du Rietz) Lamb ≡ *Usnea antarctica* Du Reitz). Not present in Tasmania (Walker 1985).

Neuropogon ciliatus (Nyl.) Krempelh. [≡ *Usnea ciliata* (Nyl.) Du Rietz]. Occurrence in Tasmania doubtful (Walker 1985).

Neuropogon melaxanthus (Ach.) Nyl. [≡ *Usnea aurantiaco-atra* (Jacqu.) Bory]. Not present in Tasmania (Walker 1985).

Neuropogon sulphureus (Th. Fr.) Hellbom (≡ *Usnea sphacelata* R. Br.) Not present in Tasmania (Walker 1985).

Ochrolechia pseudotartarea (Vainio) Verseghy. Record doubtful.

Pannaria imbricata Nyl. ≡ *Psoroma asperellum* Nyl.

Parmelia adpressa Krempelh. (≡ *Xanthoparmelia succedans* Elix & Johnston). Not present in Tasmania (Elix *et al.* 1986).

Parmelia alpicola Th. Fr. Not present in Tasmania. Possibly misapplied to *Neofuscelia stygioides* (Nyl. ex Crombie) Esslinger.

Parmelia amplexula Stirton ≡ *Xanthoparmelia amplexula* (Stirton) Elix & Johnston

Parmelia antleriformis Elix ≡ *Xanthoparmelia antleriformis* (Elix) Elix & Johnston

Parmelia australiensis Crombie [≡ *Xanthoparmelia australiensis* (Crombie) Hale]. Not present in Tasmania.

Parmelia bungendorensis Elix ≡ *Xanthoparmelia bungendorensis* (Elix) Elix & Johnston

Parmelia caperata (L.) Ach. Refers to *Flavoparmelia haysomii* (Dodge) Hale in Australia.

***Parmelia concors* Krempelh.** ≡ *Parmotrema cristiferum* (Taylor) Hale

Parmelia conferta Taylor ≡ *Hypogymnia billardierei* (Mont.) R. Filson

Parmelia conlabrosa Hale. Not recorded for Tasmania by Elix & Stevens (1979).

Parmelia conspersa (Ach.) Ach. Not present in Tasmania and generally misapplied in the past to many species of *Xanthoparmelia*. Two subspecific taxa, *P. conspersa* var. *incisa* (Taylor) Zahlbr. and *P. conspersa* var. *laxa* Müll. Arg. are synonyms of *Xanthoparmelia tasmanica* (J.D. Hook. & Taylor) Hale.

Parmelia cristifera Taylor ≡ *Parmotrema cristiferum* (Taylor) Hale

Parmelia hookeri Taylor. The description in the original reference (Wilson 1893) suggests that this record refers to the common species *Parmelina stevensiana* Elix & Johnston.

Parmelia hypoclystoides (Müll. Arg.) Gyelnik ≡ *Xanthoparmelia scabrosa* (Taylor) Hale

Parmelia inaequalis Taylor ≡ *Pannoparmelia angustata* (Pers. in Gaud.) Zahlbr.

Parmelia jelineckii Krempelh. ≡ *Flavoparmelia rutidota* (J.D. Hook. & Taylor) Hale

Parmelia laceratula Nyl. [≡ *Punctelia rudecta* (Ach.) Krog.]. Not present in Tasmania.

Parmelia moniliformis J.D. Hook. ≡ *Pannoparmelia angustata* (Pers. in Gaud.) Zahlbr.

Parmelia mundata Nyl. var. *pulverata* Nyl. ≡ *Hypogymnia pulverata* (Nyl.) Elix

Parmelia neorimalis Elix & P. Armstrong [≡ *Xanthoparmelia neorimalis* (Elix & P. Armstrong) Elix & Johnston]. Not present in Tasmania (Elix *et al.* 1986).

Parmelia ochroleuca Müll. Arg. ≡ *Flavoparmelia rutidota* (J.D. Hook. & Taylor) Hale

Parmelia olivacea (L.) Ach. Not present in Tasmania and erroneously applied to several brown species of *Parmelia s. lat.*

Parmelia omphalodes (L.) Ach. Refers to *P. signifera* Nyl. in Tasmania (Filson 1986).

Parmelia perforata (Wulfen) Ach. The description of the taxon referred to under this name by Wilson (1893) suggested it is *Parmotrema reticulatum* (Taylor) Choisy.

Parmelia perlata (Huds.) Ach. ≡ *Parmotrema chinense* (Osbeck) Hale & Ahti

Parmelia physodes var. *sublugubris* Müll. Arg. ≡ *Hypogymnia lugubris* var. *sublugubris* (Müll. Arg.) Elix

Parmelia prolixa (Ach.) Malbr. ≡ *Neofuscelia pulla* (Ach.) Esslinger

Parmelia pruinata Müll. Arg. Refers to *Parmelina stevensiana* Elix & Johnston in Tasmania (Elix & Johnston 1986).

Parmelia quercina Willd. Not present in Tasmania. Record probably refers to *Parmelina stevensiana* Elix & Johnston.

Parmelia reptans Kurok. [≡ *Xanthoparmelia reptans* (Kurok.) Elix & Johnston]. Not present in Tasmania (Elix *et al.* 1986).

Parmelia rudecta Ach. Refers to *Punctelia subflava* (Taylor) Elix & Johnston in Australia.

Parmelia saxatilis (L.) Ach. Not present in Tasmania (Galloway & Elix 1983).

Parmelia scabropustulata Elix ≡ *Xanthoparmelia scabrosa* (Taylor) Hale

Parmelia splachnirima J.D. Hook. & Taylor ≡ *Knightiella splachnirima* (J.D. Hook. & Taylor) Gyelnik

Parmelia stenophylla (Ach.) Heug. ≡ *Xanthoparmelia digitiformis* (Elix & P. Armstrong) R. Filson

Parmelia subalbicans Stirton. Not present in Tasmania.

Parmelia subcaperatula Nyl. ≡ *Flavoparmelia rutidota* (J.D. Hook. & Taylor) Hale

Parmelia subglabra Räsänen ≡ *Melanelia subglabra* (Räsänen) Esslinger

Parmelia subprolixa Krempelh. ≡ *Neofuscelia pulla* (Ach.) Esslinger

Parmelia tiliacea (Hoffm.) Ach. Not present in Tasmania. The name refers to *Parmelina conlabrosa* (Hale) Elix & Johnston in Australia (Filson 1986).

Parmelia tinctina Mah. & Gill. Refers to *Xanthoparmelia isidiigera* in Tasmania (Filson 1986).

Parmelia ulophylla (Ach.) F. Wilson ≡ *Punctelia subrudecta* (Nyl.) Krog

Parmeliella amphibola (Knight) Müll. Arg. ≡ *Leioderma amphibolum* (Knight) P.M. Jørg. & D. Galloway

Parmeliella plumbea (Lightf.) Müll. Arg. Not present in Tasmania. This name has probably been misapplied to species of *Degelia* and *Coccocarpia*.

Parmeliella triptophylla (Ach.) Müll. Arg. Jørgensen (1978) observed that no reliable Southern Hemisphere records of this European species have been traced.

Parmeliopsis semiviridis F. Muell. ex Nyl. [≡ *Chondropsis semiviridis* (F. Muell. ex Nyl.) Nyl. ex Crombie]. Not present in Tasmania.

Parmotrema cooperi (J. Stein & Zahlbr.) Sérusiaux. An African species (Hale 1965, Krog & Swinscow 1981) whose occurrence in Tasmania seems very doubtful.

Peltigera erumpens (Taylor) Vainio ≡ *Peltigera didactyla* (With.) Laundon

Peltigera spuria (Ach.) DC. ≡ *P. didactyla* (With.) Laundon

Perforaria peponula (Müll. Arg.) Müll. Arg. ≡ *Coccotrema cucurbitula* (Mont.) Müll. Arg.

Pertusaria ascripta Stirton. Not in Tasmania Previously misidentified for *P. truncata* Krempelh.

Pertusaria leioplaca (Ach.) DC. ≡ *P. leucostoma* (Bernh.) Mass. (Hanko 1983).

Pertusaria leioplaca var. *octospora* Nyl. ≡ *P. alpina* Hepp ex Ahles (Filson 1986).

Pertusaria nothofagi Zahlbr. ≡ *P. truncata* Krempelh.

Phaeographis dendritica (Ach.) Müll. Arg. Record doubtful.

Phlyctella wilsonii Müll. Arg. ≡ *Phlyctis subuncinata* Stirton

Phyllopsora melanocarpa Müll. Arg. ≡ *Neophyllis melacarpa* (F. Wilson) F. Wilson

Physcia astroidea (Clem.) Nyl. ≡ *P. clementei* (Sm.) Lynge

Physcia endococcinoides Poelt ≡ *Phaeophyscia endococcinoides* (Poelt) Esslinger

Physcia picta (Sw.) Nyl. ∫ *Dirinária picta* (Sw.) Clem. & Shear

Physciopsis adglutinata (Flörke) Choisy ≡ *Hyperphyscia adglutinata* (Flörke) Mayrhofer & Poelt

Pilophorus conglomeratus F. Wilson ≡ *Metus conglomeratus* (F. Wilson) D. Galloway & P. James

Polychidium umhausense (Auersw.) Henssen. Misdetermined for *Dendriscocaulon dendriothamnodes* Dughi in D. Galloway.

Pseudocyphellaria amphisticta Knight. Record (by Bratt & Cashin 1976) refers to *P. argyracea* (Delise) Vainio.

Pseudocyphellaria australiensis H. Magn. ≡ *P. neglecta* (Müll. Arg.) H. Magn.

Pseudocyphellaria carpoloma (Delise) Vainio. Although recorded by several early workers (see Wetmore 1963), the species does not appear to occur in Tasmania and the name appears to have been misapplied to other taxa in the *P. faveolata* group.

Pseudocyphellaria cellulifera (J.D. Hook.) Gyelnik ≡ *P. faveolata* (Delise) Malme.

Pseudocyphellaria cinnamomea (A. Rich.) Vainio. Recorded by early authors but all specimens examined to date are of *P. dissimilis* (Nyl.) D. Galloway & P. James, a closely related, very common species.

Pseudocyphellaria delisea (Fée) D. Galloway & P. James ≡ *P. glabra* (J.D. Hook. & Taylor) Dodge

Pseudocyphellaria dissimulata (Nyl.) Vainio. Refers to *P. multifida* (Nyl.) D. Galloway & P. James

Pseudocyphellaria durvillei (Delise) Vainio. Misapplied to *P. coronata* (Müll. Arg.) Malme (see Galloway & James 1977).

Pseudocyphellaria endochrysa (Delise) Vainio. Misapplied to *P. coronata* (Müll. Arg.) Malme.

Pseudocyphellaria flavicans (J.D. Hook. & Taylor) Vainio. Not present in Tasmania and the name has probably been misapplied to *P. colensoi* (Church. Bab.) Vainio.

Pseudocyphellaria flotowiana (Laurer) Malme ≡ *P. billardierei* (Delise) Räsänen

Pseudocyphellaria fossulata (Dufour) Malme ≡ *P. faveolata* (Delise) Malme

Pseudocyphellaria freycinetii (Delise) Malme. A South Amercian species, widely confused with *P. glabra* (J.D. Hook. & Taylor) Dodge in Australasia (Galloway 1985).

Pseudocyphellaria gilva (Ach.) Malme ≡ P. crocata (L.) Vainio

Pseudocyphellaria hirta (Stirton) D. Galloway & P. James ≡ *P. coronata* (Müll. Arg.) Malme

Pseudocyphellaria impressa (J.D. Hook. & Taylor) Vainio ≡ *P. faveolata* (Delise) Malme

Pseudocyphellaria mougeotiana (Delise) Vainio ≡ *P. crocata* (L.) Vainio

Pseudocyphellaria orygmaea (Ach.) Malme. Refers to *P. coronata* (Müll. Arg.) Malme

Pseudocyphellaria physciospora (J.D. Hook.) Malme ≡ *P. faveolata* (Delise) Malme

Pseudocyphellaria polyschista (Meyen & Flotow) Zahlbr. Listed for Tasmania by Filson (1986) but record appears doubtful.

Pseudocyphellaria prolificans (Nyl.) Vainio. Doubtful record presumed to be based on a misidentification.

Pseudocyphellaria richardi (Mont.) Massal. ≡ *P. billardierei* (Delise) Räsänen

Pseudocyphellaria subvariabilis (Nyl.) Vainio ≡ *P. multifida* (Nyl.) D. Galloway & P. James

***Pseudopyrenula glactina* Shirley** ≡ *Pyrenula galactina* (Shirley) Kantvilas

Psoroma caliginosum Stirton. Refers to *P. pholidotoides* (Nyl.) Trevis. in Tasmania.

Psoroma contextum Stirton. Misapplied by Bratt & Cashin (1976) to *P. pholidotoides* (Nyl.) Trevis.

Psoroma imbricatum (Nyl.) J. Murray ≡ *P. asperellum* Nyl.

Psoroma reticulatum (Hue) Zahlbr. ≡ *P. pholidotoides* (Nyl.) Trevis.

Psoroma sphinctrinum var. *leprolomum* Nyl. ≡ *P. leprolomum* (Nyl.) Räsänen

Psoroma sphinctrinum var. *microphyllizans* Nyl. ≡ *P. microphyllozans* (Nyl.) D. Galloway

Psoromaria descendens (Nyl.) Nyl. ≡ *Psoromidium aleuroides* (Stirton) D. Galloway

Ramalina brevis F. Wilson var. *brevissima* F. Wilson ≡ *R. fissa* (Müll. Arg.) Vainio

Ramalina calicaris (L.) Fr. Refers to *R. glaucescens* Krempelh.

Ramalina ecklonii (Spreng.) Meyen & Flotow ≡ *R. celastri* (Spreng.) Krog & Swinsc.

Ramalina fastigiata (Pers.) Ach. Refers to *R. glaucescens* Krempelh.

Ramalina fraxinea (L.) Ach. var. *brevissima* F. Wilson ≡ *R. fissa* (Müll. Arg.) Vainio

Ramalina fraxinea f. *platyna* Nyl. ≡ *R. fissa* (Müll. Arg.) Vainio

Ramalina geniculata J.D. Hook. & Taylor ≡ *R. inflata* (J.D. Hook. & Taylor) J.D. Hook. & Taylor

Ramalina inflata var. *gracilis* Müll. Arg. ≡ *R. inflata* (J.D. Hook. & Taylor) J.D. Hook. & Taylor

Ramalina leiodea (Nyl.) Nyl. [≡ *R. subfraxinea* var. *leiodea* (Nyl.) Stevens]. Not present in Tasmania.

Ramalina membranacea (Laurer) Mont. Not present in Australia. Record probably refers to *R. celastri* (Sprengel) Krog & Swinsc.

Ramalina pollinaria (Liljebl.) Ach. Misapplied to *R. unilateralis* F. Wilson.

Ramalina pusilla le Prev. ≡ *R. inflata* ssp. *australis* N. Stevens

Ramalina tasmanica Nyl. ≡ *R. inflata* (J.D. Hook. & Taylor) J.D. Hook. & Taylor

Ramalina yemensis (Ach.) Nyl. ≡ *R. celastri* (Sprengel) Krog & Swinsc.

Ramalina yemensis ssp. *ovalis* (J.D. Hook. & Taylor) Zahlbr. ≡ *R. celastri* ssp. *ovalis* (J.D. Hook. & Taylor) N. Stevens

Siphula coriacea Taylor ex Nyl. Not present in Tasmania.

Siphula dissoluta Nyl. Not present in Tasmania. Previously misapplied to some forms of *S. decumbens* Nyl. s. lat.

Siphula pteruloides Nyl. Misapplied to *S. complanata*. (J.D. Hook. & Taylor) R Sant.

Siphula torulosa (Ach.) Nyl. Generally misapplied to *S. decumbens* Nyl. (see Mathey 1974).

Sphaerophorus australis Laurer ≡ *S. melanocarpus* (Sw.) DC.

Sphaerophorus compressus Ach. ≡ *S. melanocarpus* (Sw.) DC.

Sphaerophorus fragilis (L.) Pers. Not present in Tasmania (see Kantvilas 1988).

Sphaerophorus globosus (Huds.) Vainio. Not present in Tasmania.

Stereocaulon colensoi Church. Bab. Not present in Tasmania.

Stereocaulon coralloides Fr. (≡ *S. dactylophyllum* Flörke). Not present in Tasmania.

Stereocaulon denudatum Flörke ≡ *S. vesuvianum* Pers.

Stereocaulon gracilescens Nyl. [≡ *Leprocaulon gracilescens* (Nyl.) Lamb & Ward]. Not present in Tasmania (Lamb & Ward 1974).

Stereocaulon kilmandscharoense Stein ≡ *S. vesuvianum* Pers.

***Stereocaulon leptaleum* Nyl.** ≡ *S. corticatulum* Nyl.

Stereocaulon macrocarpum Rich. ≡ *S. ramulosum* (Sw.) Räuschel

***Stereocaulon macrocarpoides* Nyl.** ≡ *S. ramulosum* (Sw.) Räuschel

Stereocaulon proximum Nyl. ≡ *S. ramulosum* (Sw.) Räuschel

Sticta cetrarioides J.D. Hook. ≡ *Heterodea muelleri* (Hampe) Nyl.

Sticta cinereoglauca J.D. Hook. & Taylor. Not present in Tasmania.

Sticta filicina Ach. [≡ *S. filix* (Sw.) Nyl.] Not present in Tasmania. Most Tasmanian records of species of *Sticta* with a green photobiont appear to be misidentifications of *S. stipitata* Knight.

Sticta filix (Sw.) Nyl. Not present in Tasmania (see above under *S. filicina*).

Sticta fragillima Church. Bab. Probably misapplied to *Pseudocyphellaria dissimilis* (Nyl.) D. Galloway & P. James.

Sticta fulvocinerea Mont. Refers to *Pseudocyphellaria glabra* (J.D. Hook. & Taylor) Dodge.

Sticta latifrons Rich. Not present in Tasmania.

Sticta linearis J.D. Hook. & Taylor ≡ *Pseudocyphellaria billardierei* (Delise) Räsänen

Sticta muelleri Hampe ≡ *Heterodea muelleri* (Hampe) Nyl.

Sticta shirleyana Müll. Arg. ≡ *S. stipitata* Knight

Teloschistes chrysophthalmus var. *sieberianus* (Laurer) Müll. Arg. ≡ *T. sieberianus* (Laurer) Hillm.

Teloschistes flavicans var. *subexilis* (Nyl.) F. Wilson ≡ *T. spinosus* (J.D. Hook. & Taylor) J. Murray

Thelidea corrugata Hue ≡ *Knightiella splachnirima* (J.D. Hook. & Taylor) Gyelnik

Thysanothecium hyalinum Mont. & Berk. ≡ *T. scutellatum* (Fr.) D. Galloway

Umbilicaria cinerascens (Ach.) Nyl. Misapplied to *U. subglabra* (Nyl.) Harm. (Blackman *et al.* 1974).

Umbilicaria proboscoidea (L.) Schrad. Not present in Tasmania (Blackman *et al.* 1974).

Usnea acromelana var. *decipiens* (Lamb) Lamb ≡ *U. acromelana* Stirton

Usnea acromelana var. *inactiva* Lamb ≡ *U. torulosa* (Müll. Arg.) Zahlbr.

Usnea antarctica Du Reitz. Not present in Tasmania (Walker 1985).
Usnea arida Motyka. Not present in Tasmania (G.N. Stevens, pers. comm.). Previous use of this name in the literature refers mostly to *U. leprosa* Motyka.
Usnea articulata Fr. Occurrence in Tasmania doubtful (G.N. Stevens, pers. comm.).
Usnea barbata (L.) Wigg. Refers to *U. scabrida* Taylor.
Usnea dasypoga (Ach.) Hornem. Not present in Tasmania (G.N. Stevens, pers. comm.).
Usnea dasypogoides Nyl. ex Crombie. Not present in Tasmania (G.N. Stevens, pers. comm.).
Usnea flexilis Stirton. Occurrence in Tasmania doubtful.
Usnea florida (L.) Wigg. Refers to *U. scabrida* Taylor.
Usnea glomerata Motyka ≡ *U. torulosa* (Müll. Arg.) Zahlbr.
Usnea longissima Ach. Occurrence in Tasmania doubtful (G.N. Stevens, pers. comm.).
Usnea microcarpioides (Müll. Arg.) Motyka ≡ *U. ramulosissima* Stevens & Rogers
Usnea melaxantha Ach. [≡ *U. aurantiaco-atra* (Jacq.) Bory]. Not present in Tasmania (Walker 1985).
Usnea plicata (L.) Wigg. Occurrence in Tasmania doubtful (G.N. Stevens, pers. comm.).
Usnea rubescens Stirton ≡ *U. rubicunda* Stirton
Usnea sphacelata R.Br. Not present in Tasmania (Walker 1985).
Usnea straminea Müll. Arg. Not present in Tasmania (G.N. Stevens, pers. comm.).
Usnea subfusca Stirton. Refers to species of *Usnea* subgen. *Neuropogon* (G.N. Stevens, pers. comm.) of which only two taxa occur in Tasmania, *U. acromelana* and *U. subcapillaris*.
***Usnea tasmanica* (Müll. Arg.) Zahlbr.** ≡ *U. baileyi* (Stirton) Zahlbr.
Xanthoria ectanea (Ach.) Räsänen ex R. Filson ≡ *X. ligulata* (Körber) P. James in Australia.
Xanthoria lychnea (Ach.) Fr. [≡ *X. candelaria* (L.) Th. Fr.]. Not present in Tasmania.
***Xanthoria spinosa* (J.D. Hook. & Taylor) Du Rietz** ≡ *Teloschistes spinosus* (J.D. Hook. & Taylor) J. Murray.
***Xanthoria spinulosa* (Krempelh.) Hillm.** ≡ *Teloschistes spinosus* (J.D. Hook. & Taylor) J. Murray.

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REFERENCES

Ahti, T., 1961: Taxonomic studies on reindeer lichens (*Cladonia* subgenus *Cladina*). *Ann. Bot. Soc. Zool. Bot. Fenn. "Vanamo"* 32: 1–160.
Ahti, T., 1980: Taxonomic revision of *Cladonia gracilis* and its allies. *Ann. Bot. Fennici* 17: 195–243.
Ahti, T., 1983: Taxonomic notes on some American species of the lichen genus *Cladonia*. *Ann. Bot. Fennici* 20: 1–7.
Ahti, T., 1984: The status of *Cladina* as a genus segregated from *Cladonia*. *Beih. Nova Hedwigia* 79: 25–61.
Archer, A.W., 1980: A new Australian lichen: *Cladonia kuringaiensis*. *Muelleria* 4: 273–275.
Archer, A.W., 1982: A new Australian lichen: *Cladonia sulcata*. *Muelleria* 5: 115–117.
Archer, A.W., 1984: Three new Australian lichens: *Cladonia celata*, *C. praetermissa* and *C. wilsonii*. *Muelleria* 5: 271–275.
Archer, A.W., 1985: Two new lichens: *Cladonia bimberiensis* and *C. weymouthii*. *Muelleria* 6: 93–95.
Archer, A.W., 1986: The chemistry and distribution of *Cladonia capitellata* (J.D. Hook. & Taylor) Church. Bab. (Lichens) in Australia. *Proc. Linn. Soc. N.S.W.* 108: 191–194.
Archer, A.W., 1987: Two new lichens: *Cladonia squamosula* var. *subsquamosula* and *C. sulcata* var. *striata* with notes on chemotaxonomy within the species. *Muelleria* 6: 383–388.
Archer, A.W., 1988a: The lichen genus *Cladonia* section *Cocciferae* in Australia. *Proc. Linn. Soc. N.S.W.* 110: 205–213.
Archer, A.W., 1988b: Two new lichens: *Cladonia paeminosa* and *C. humilis* var. *bourgeanica*. *Muelleria* 7: 1–5.
Archer, A.W. & Bartlett, J.K., 1986: New species and distributions of the lichen genus *Cladonia* in New Zealand together with a revised key. *N.Z. J. Bot.* 24: 581–587.
Arvidsson, L., 1982: A monograph of the lichen genus *Coccocarpia*. *Opera Bot.* 67: 1–96.
Arvidsson, L. & Galloway, D.J., 1979: The lichen genus *Coccocarpia* in New Zealand. *Bot. Notiser* 132: 239–246.
Arvidsson, L. & Galloway, D.J., 1981: *Degelia*, a new lichen genus in the Pannariaceae. *Lichenologist* 13: 27–50.
Babington, C. & Mitten, W., 1859: Lichenes. *In* Hooker, J.D. (Ed.): *FLORA TASMANIAE*, vol.II. Lovell-Reeve, London: 343–354.

BLACKMAN, A.J., BRATT, G.C. & CASHIN, J.A., 1973: Distribution and chemistry of *Heterodea muelleri*. *Bryologist* 76: 410–413.

BLACKMAN, A.J., BRATT, G.C. & CASHIN, J.A., 1974: Umbilicariaceae in Tasmania. *Lichenologist* 6: 112–114.

BRATT, G.C., BLACKMAN, A.J. & CASHIN, J.A., 1976: The genus *Anzia* in Tasmania. *Lichenologist* 8: 69–77.

BRATT, G.C. & CASHIN, J.A., 1975: Additions to the lichen flora of Tasmania I. *Pap. Proc. R. Soc. Tasm.* 109: 17–20.

BRATT, G.C. & CASHIN, J.A., 1976: Additions to the lichen flora of Tasmania II. *Pap. Proc. R. Soc. Tasm.* 110: 139–148.

CHRISTENSEN, S.N., 1987: Morphological and chemical variation in the *Cladonia macilentalbacillaris* aggregate in Denmark. *Lichenologist* 19: 61–69.

CROMBIE, J.M., 1880: Enumeration of lichens in the herbarium of Robert Brown, with descriptions of new species. *J. Linn. Soc. Lond. (Botany)* 17: 390–401.

DEGELIUS, G., 1974: The lichen genus *Collema* with special reference to extra-European species. *Symb. Bot. Upsal.* 20: 1–215.

DÖBBELER, P., 1981: Moosbewohnende Ascomyceten V. Die auf *Dawsonia* vorkommenden arten der Botanischen Staatssammlung München. *Mitt. Bot. München* 17: 393–474.

DÖBBELER, P., POELT, J. & VEZDA, A., 1985: *Lopadium hepaticola* spec. nov. ein moosparasitisches echtes *Lopadium* von der Sudhalbkugel. *Herzogia* 7: 81–91.

ELIX, J.A., 1979: A taxonomic revision of the lichen genus *Hypogymnia* in Australasia. *Brunonia* 2: 175–245.

ELIX, J.A., 1981a: Further new species of *Parmelia* (Lichens) from Australia. *Aust. J. Bot.* 29: 17–23.

ELIX, J.A., 1981b: New species of *Parmelia* subgen. *Xanthoparmelia* (Lichens) from Australia and New Zealand. *Aust. J. Bot.* 29: 349–376.

ELIX, J.A. & ARMSTRONG, P.M., 1983: Further new species of *Parmelia* subgen. *Xanthoparmelia* (Lichens) from Australia and New Zealand. *Aust. J. Bot.* 31: 467–483.

ELIX, J.A. & JOHNSTON, J., 1986: New species of *Parmelina* (Lichenised Ascomycotina) from Australia and New Zealand. *Brunonia* 9: 155–161.

ELIX, J.A. & JOHNSTON, J., 1987: New species and new records of *Xanthoparmelia* (lichenized Ascomycotina) from Australia. *Mycotaxon* 29: 359–372.

ELIX, J.A. & JOHNSTON, J., 1988: New species in the lichen family Parmeliaceae (Ascomycotina) from the southern hemisphere. *Mycotaxon* 31: 491–510.

ELIX, J.A., JOHNSTON, J. & ARMSTRONG, P.M., 1986: A revision of the lichen genus *Xanthoparmelia* in Australasia. *Bull. Br. Mus. Nat. Hist. (Bot.)* 15: 163–362.

ELIX, J.A. & STEVENS, G.N., 1979: New species of *Parmelia* (Lichens) from Australia. *Aust. J. Bot.* 27: 873–883.

ELIX, J.A. & STREIMANN, H., 1982: New lichen records for Australia. *J. Hattori Bot. Lab.* 51: 69–97.

ESSLINGER, T.L., 1977: A chemosystematic revision of the brown *Parmeliae*. *J. Hattori Bot. Lab.* 42: 1–211.

FILSON, R.B., 1969: A review of the genera *Teloschistes* and *Xanthoria* in the lichen family Teloschistaceae in Australia. *Muelleria* 2: 65–115.

FILSON, R.B., 1978: A revision of the genus *Heterodea*. *Lichenologist* 10: 13–25.

FILSON, R.B., 1981: A revision of the lichen genus *Cladia*. *J. Hattori Bot. Lab.* 49: 1–75.

FILSON, R.B., 1982: A contribution on the genus *Parmelia* (Lichens) in southern Australia. *Aust. J. Bot.* 30: 511–582.

FILSON, R.B., 1983: *CHECKLIST OF AUSTRALIAN LICHENS*. National Herbarium of Victoria, Melbourne.

FILSON, R.B., 1984: *Xanthoparmelia elixii* (Lichens), a new species from Australia and New Zealand. *Brunonia* 7: 203–205.

FILSON, R.B., 1986: *CHECKLIST OF AUSTRALIAN LICHENS*. Second edition, National Herbarium of Victoria, Melbourne.

FILSON, R.B., 1988a: The lichen genera *Heppia* and *Peltula* in Australia. *Muelleria* 6: 495–517.

FILSON, R.B., 1988b: *CHECKLIST OF AUSTRALIAN LICHENS*. Third edition, National Herbarium of Victoria, Melbourne.

FILSON, R.B. & ROGERS, R.W, 1979: *LICHENS OF SOUTH AUSTRALIA*. South Australian Government Printer, Adelaide.

GALLOWAY, D.J., 1974: A bibliography of New Zealand lichenology. *N.Z. J. Bot.* 12: 397–422.

GALLOWAY, D.J., 1978: *Anzia* and *Pannoparmelia* (Lichenes) in New Zealand. *N.Z. J. Bot.* 16: 261–270.

GALLOWAY, D.J., 1980a: Notes on the lichen genus *Baeomyces* in New Zealand. *Bot. Notiser* 133: 77–83.

GALLOWAY, D.J., 1980b: The lichen genera *Argopsis* and *Stereocaulon* in New Zealand. *Bot. Notiser* 133: 261–279.

GALLOWAY, D.J., 1980c: *Xanthoparmelia* and *Chondropsis* (Lichenes) in New Zealand. *N.Z. J. Bot.* 18: 525–552.

GALLOWAY, D.J., 1981: The lichen genus *Lobaria* in New Zealand. *Nova Hedwigia* 34: 317–331.

GALLOWAY, D.J., 1983a: Nomenclatural notes on *Pseudocyphellaria* I. The identity of *Pseudocyphellaria neglecta*. *Lichenologist* 15: 307–308.

GALLOWAY, D.J., 1983b: New taxa in the New Zealand lichen flora. *N.Z. J. Bot.* 21: 191–200.

GALLOWAY, D.J., 1985a: Nomenclature notes on *Pseudocyphellaria* II. Some southern hemisphere taxa. *Lichenologist* 17: 303–307.

GALLOWAY, D.J., 1985b: *FLORA OF NEW ZEALAND: LICHENS*. Government Printer, Wellington.

GALLOWAY, D.J., 1988: Studies in *Pseudocyphellaria* (lichens) I. The New Zealand species. *Bull. Br. Mus. Nat. Hist. (Bot.)* 17: 1–267.

GALLOWAY, D.J. & BARTLETT, J.K., 1983: The lichen genus *Thysanothecium* Mont. & Berk. in New Zealand. *Nova Hedwigia* 36: 381–398.

GALLOWAY, D.J. & BARTLETT, J.K., 1986: *Arthroraphis*

Th. Fr. (lichenised *Ascomycotina*) in New Zealand. *N.Z. J. Bot.* 24: 393–402.

GALLOWAY, D.J. & ELIX, J.A., 1980: *Knightiella* Müll. Arg., a monotypic lichen genus from Australasia. *N.Z. J. Bot.* 18: 481–486.

GALLOWAY, D.J. & ELIX, J.A., 1983: The lichen genera *Parmelia* Ach. and *Punctelia* Krog in Australasia. *N.Z. J. Bot.* 21: 397–420.

GALLOWAY, D.J. & ELIX, J.A., 1984: Additional notes on *Parmelia* and *Punctelia* (lichenised Ascomycotina) in Australasia. *N.Z. J. Bot.* 22: 441–445.

GALLOWAY, D.J. & JAMES, P.W., 1977: *Pseudocyphellaria berberina*: notes on its discovery and synonymy. *Lichenologist* 9: 95–105.

GALLOWAY, D.J. & JAMES, P.W., 1980: Nomenclatural notes on *Pseudocyphellaria* in New Zealand. *Lichenologist* 12: 291–303.

GALLOWAY, D.J. & JAMES, P.W., 1985: The lichen genus *Psoromidium* Stirton. *Lichenologist* 17: 173–188.

GALLOWAY, D.J. & JAMES, P.W., 1987: *Metus*, a new austral lichen genus and notes on an australasian species of *Pycnothelia*. *Notes R.B.G. Edinb.* 44: 561–579.

GALLOWAY, D.J., JAMES, P.W. & WILKINS, A.L., 1983: Further nomenclatural and chemical notes on *Pseudocyphellaria* in New Zealand. *Lichenologist* 15: 135–146.

GALLOWAY, D.J. & JØRGENSEN, P.M., 1987: Studies in the lichen family Pannariaceae II. The genus *Leioderma* Nyl. *Lichenologist* 19: 345–400.

GALLOWAY, D.J., LAMB, I.M. & BRATT, G.C., 1976: Two new species of *Stereocaulon* from New Zealand and Tasmania. *Lichenologist* 8: 61–67.

HAFELLNER, J., 1981: Monographie der Flechtengattung *Letrouitia* (Lecanorales, Teloschistineae). *Nova Hedwigia* 35: 645–729.

HALE, M.E., 1965: A monograph of *Parmelia* subgenus *Amphigymnia*. *Contrib. U.S. Nat. Herb.* 36: 193–358.

HALE, M.E., 1975: A monograph of the lichen genus *Relicina* (Parmeliaceae). *Smithson. Contrib. Bot.* 26: 1–32.

HALE, M.E., 1976: A monograph of the lichen genus *Pseudoparmelia* Lynge. *Smithson. Contrib. Bot.* 31: 1–62.

HALE, M.E., 1988: A monograph of the lichen genus *Parmelia* Acharius *sensu stricto* (Ascomycotina: Parmeliaceae). *Smithson. Contrib. Bot.* 66: 1–55.

HAMPE, E., 1852: Plantae Muellerianae, Beitrag Flora Sudaustraliens. Lichenes. *Linnaea* 25: 709–712.

HANKO, B., 1983: Die chemotypen der flechtengattung *Pertusaria* in Europa. *Bibliotheca Lichenologica* 19: 1–297.

HAWKSWORTH, D.L., 1972: Regional studies in *Alectoria* (Lichenes) II. The British species. *Lichenologist* 5: 181–261.

HAYWARD, G.C., 1977: Taxonomy of the lichen families Graphidaceae and Opegraphaceae in New Zealand. *N.Z. J. Bot.* 15: 565–584.

HENSSEN, A., 1963: Eine revision der flechtenfamilien Lichinaceae und Ephebaceae. *Symb. Bot. Upsal.* 18: 1–123.

HENSSEN, A., 1969: Three non-marine species of the genus *Lichina*. *Lichenologist* 4: 88–98.

HENSSEN, A. & KANTVILAS, G., 1985: *Wawea fruticulosa*, a new genus and species from the Southern Hemisphere. *Lichenologist* 17: 85–97.

HENSSEN, A., VOBIS, G. & RENNER, B., 1982: New species of *Roccellinastrum* with an emendation of the genus. *Nord. J. Bot.* 2: 587–599.

HERTEL, H., 1984: Über saxicole, lecideoide Flechten der Subantarktis. *Beih. Nova Hedwigia* 79: 399–499.

HERTEL, H., 1987: Bemerkenswerte Funde südhemisphärischer, saxicoler Arten der Sammelgattung *Lecidea*. *Mitt. Bot. München.* 23: 321–340.

JAMES, P.W. & HENSSEN, A., 1975: A new species of *Psoroma* with sorediate cephalodia. *Lichenologist* 7: 143–147.

JØRGENSEN, P.M., 1978: The lichen family Pannariaceae in Europe. *Opera Bot.* 45: 1–124.

KANTVILAS, G., 1985: Studies on Tasmanian rainforest lichens. Unpubl. Ph.D. thesis, Univ. Tasm.

KANTVILAS, G., 1987: *Siphula jamesii*, a new lichen from south-western Tasmania. *Nord. J. Bot.* 7: 585–588.

KANTVILAS, G., 1988: A re-examination of John Shirley's collection of Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* 122: 59–67.

KANTVILAS, G. & ELIX, J.A., 1987: A new species of *Cladia* (lichenized Ascomycotina) from Tasmania. *Mycotaxon* 29: 199–205.

KANTVILAS, G. & JAMES, P.W., 1987: The macrolichens of Tasmanian rainforest: key and notes. *Lichenologist* 19: 1–28.

KANTVILAS, G., JAMES, P.W. & JARMAN, S.J., 1985: Macrolichens in Tasmanian rainforests. *Lichenologist* 17: 67–83.

KANTVILAS, G. & JARMAN, S.J., 1988: Lichens of buttongrass (*Gymnoschoenus*) moorland in Tasmania. *Pap. Proc. R. Soc. Tasm.* 122: 1–17.

KANTVILAS, G. & VEZDA, A., 1988: A new lichenised species of *Arthonia* from south-western Tasmania. *Aust. Syst. Bot.* 1: 189–190.

KÄRNEFELT, I., 1979: The brown fruticose species of *Cetraria*. *Opera Bot.* 46: 1–150.

KROG, H. & SWINSCOW, T.D.V., 1981: *Parmelia* subgenus *Amphigymnia* (lichens) in East Africa. *Bull. Br. Mus. Nat. Hist. (Bot.)* 9: 143–231.

LAMB, I.M. & WARD, A., 1974: A preliminary conspectus of the species attributed to the imperfect lichen genus *Leprocaulon* Nyl. *J. Hattori Bot. Lab.* 38: 499–553.

LAUNDON, J.R., 1981: The species of *Chrysothrix*. *Lichenologist* 13: 101–122.

LUMBSCH, H.T., 1987: Eine neue Subspecies in der Flechtengattung *Diploschistes* aus der Südhemisphare. *Herzogia* 7: 601–608.

LUMBSCH, H.T., 1988a: Additional lichen records from Australia. 2. *Austral. Lichen. Newsletter* 22: 6–7.

LUMBSCH, H.T., 1988b: Additional lichen records from Australia. 3. *Austral. Lichen. Newsletter* 23: 3–4.

MARTIN, W., 1962: Notes on some New Zealand species of *Cladonia* with descriptions of two new species and one new form. *Trans. Roy. Soc. N.Z. (Bot.)* 2: 39–44.

MATHEY, A., 1974: Contribution à l'étude du genre *Siphula* (Lichens) en Afrique. *Nova Hedwigia* 22: 795–878.

MAYRHOFER, H., 1983: The saxicolous species of *Rinodina* in New Zealand. *Lichenologist* 15: 267–282.

MAYRHOFER, H., 1984: The saxicolous species of *Dimelaena*, *Rinodina* and *Rinodinella* in Australia. *Beih. Nova Hedwigia* 79: 511–535.

MÜLLER, J., 1887: Revisio lichenum australiensium Krempelhuberi. *Flora* 70: 113–118.

OHLSSON, K., 1974: A revision of the lichen genus *Sphaerophorus*. Unpubl. thesis, Michigan State Univ.

PETERSEN, R.H. & KANTVILAS, G., 1986: Three lichen-forming Clavarioid fungi from Tasmania. *Aust. J. Bot.* 34: 217–222.

RÄSÄNEN, V., 1944: Lichens novi II. *Soumal. eläin-ja Kasvit, seur. van. Julk.* 21: 1–6.

ROGERS, R.W., 1982: The corticolous species of *Haematomma* in Australia. *Lichenologist* 14: 115–129.

ROGERS, R.W., 1985: Additional notes on *Haematomma* in Australia. *Lichenologist* 17: 207–309.

ROGERS, R.W., 1986: The genus *Pyxine* (Physciaceae, Lichenized Ascomycetes) in Australia. *Aust. J. Bot.* 34: 131–154.

SHIRLEY, J., 1893: A list of the known lichens of Tasmania. *Pap. Proc. R. Soc. Tasm.* (1892): 179–191.

SHIRLEY, J., 1894: Notes on Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* (1893): 214–219.

SIPMAN, H.J.M., 1983: A monograph of the lichen family Megalosporaceae. *Biblioth. Lich.* 18: 1–241.

SIPMAN, H.J.M., 1986: Additional notes on the lichen family Megalosporaceae. *Willdenowia* 15: 557–564.

STENROOS, S., 1988: The family Cladoniaceae in Melanesia 3. *Cladonia* sections *Helopdium*, *Perviae* and *Cladonia*. *Ann. Bot. Fennici* 25: 117–148.

STEVENS, G.N., 1986: Three new saxicolous *Ramalinae* from Australia. *Lichenologist* 18: 183–189.

STEVENS, G.N., 1987: The lichen genus *Ramalina* in Australia. *Bull. Br. Mus. Nat. Hist. (Bot.)* 16: 107–223.

TEHLER, A., 1983: The genera *Dirina* and *Roccellina* (Roccellaceae). *Opera Bot.* 70: 1–86.

TIBELL, L., 1987: Australasian Caliciales. *Symb. Bot. Upsal.* 27: 1–279.

TIMDAL, E., 1984: The genus *Hypocenomyce* (Lecanorales, Lecideaceae) with special emphasis on the Norwegian and Swedish species. *Nord. J. Bot.* 4: 83–108.

VEZDA, A., 1977: Flechtensystematische studien X. *Conotremopsis weberiana* gen. novum et sp. nova, eine neue Flechte aus der Familie Ostropaceae. *Folia Geobot. Phytotax., Praha* 12: 313–316.

VEZDA, A. & KANTVILAS, G., 1988: *Sarrameana tasmanica*, a new Tasmanian lichen. *Lichenologist* 20: 179–182.

WALKER, F.J., 1985: The lichen genus *Usnea* subgenus *Neuropogon*. *Bull. Br. Mus. Nat. Hist. (Bot.)* 13: 1–130.

WETMORE, C.M., 1963: Catalogue of the lichens of Tasmania. *Rev. Bryol. et Lichenol.* 32: 223–264.

WHITE, F.J. & JAMES, P.W., 1988: Studies on the genus *Nephroma* II. The southern temperate species. *Lichenologist* 20: 103–166.

WILKINS, A.L. & JAMES, P.W., 1979: The chemistry of *Pseudocyphellaria impressa* s. lat. in New Zealand. *Lichenologist* 11: 271–281.

WILSON, F.R.M., 1893: Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* (1892): 133–178.

YOSHIMURA, I., 1973: Notes on *Gymnoderma melacarpum* comb. nov. *J. Jap. Bot.* 48: 283–288.

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TASMANIAN SPECIES OF *RANUNCULUS* — A NEW KEY

by Y. Menadue and R. K. Crowden

(with six text-figures)

MENADUE, Y. & CROWDEN, R.K., 1989 (31:x): Tasmanian species of *Ranunculus* — a new key. *Pap. Proc. R. Soc. Tasm. 123*: 87-96. ISSN 0080-4703. Botany Department, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001.

A key to all *Ranunculus* species occurring in Tasmania is provided. Diagnostic characters are presented by means of diagrams. Ecological notes, the main distinguishing features, and chromosome numbers are given for each species.
Key Words: Ranunculus, Tasmania, chromosome number.

INTRODUCTION

Ranunculus contains more than 500 species, about 50 of which occur in Australia; Curtis & Morris (1975) record 26 species for Tasmania.

In a recent study, Menadue (1986) recognises 28 species in the State, of which 19 are native (including one cosmopolitan and eight endemics) and nine are introduced. This treatment of the genus differs from that of Curtis & Morris in that three new species are recognised, *R. prasinus*, *R. jugosus* and *R. collicolus* (Menadue & Crowden 1985), *R. inundatus* is considered not to occur in Tasmania, *R. concinnus* has been reduced to synonomy under *R. decurvus* (Menadue & Crowden 1988), and the European species *R. flammula* has been recorded from the northeast of the State.

It is generally acknowledged *Ranunculus* species may present identification difficulties because, as in many other herbaceous plant families, leaf shape and size may be subject to environmental influences or show variability as a result of polyploidy. Menadue (1986) demonstrated phenotypic plasticity in *R. nanus* and observed variability in leaf morphology in many other species, particularly the fibrous-rooted native species, e.g. *R. decurvus*, *R. pimpinellifolius*, *R. triplodontus* and *R. lappaceus*. The occurrence of polyploidy was also revealed in two native species, *R. glabrifolius* (2n = 48 and 64) and *R. amphitrichus* (2n = 48, 64 and 96), with the accompanying variability in their gross morphology.

For the most part species are not separated on the basis of a single character difference but rather on a combination of several characters. The diagnostic features used for this current key are presented by means of diagrams. Figures 1 & 2 show the basic leaf form for all species occurring in Tasmania; in most cases, at least two leaves are illustrated to show some of the variability.

The species can be divided into three groups based on the nature of the achenes: those which are lenticular and smooth, those which are lenticular and bear hairs, spines or tubercles, and those which are inflated and rough-surfaced. The shape and size of the achene is uniform within a species. A typical achene for each species is illustrated in figure 3.

Tasmanian *Ranunculus* species have six basic types of nectary or nectar-secreting pit on the upper surface in the basal half of the petal (fig. 4). The shape and size of the petals, together with the nature of the nectary (fig. 5), have proved to be very useful characters for the identification of the local species.

A description of the diagnostic features for *Ranunculus* and a key to all the Tasmanian species follow. (The basic leaf shapes used in the key are defined in figure 6.) For each species, numbered according to the key, ecological notes, main distinguishing features and chromosome numbers are presented.

DIAGNOSTIC FEATURES FOR *RANUNCULUS* L.

Annual or perennial herbs, sometimes aquatic. Stems erect or creeping. Leaves spirally arranged, often in a basal rosette, petioles having gradually tapered leaf bases and no stipules; leaf blades may be palmately lobed or divided, ternate or pinnately dissected, sometimes simple or entire (fig. 6).

FIG.1 — Leaves of the native Ranunculus *species. At least two illustrations are given for each species. Scale bar = 1 cm. (A)* R. lappaceus*; (B)* R. pascuinus*; (C)* R. scapigerus*; (D)* R. collicolus*; (E)* R. setaceus*; (F)* R. pimpinellifolius*; (G)* R. decurvus*; (H)* R. collinus*; (I)* R. pumilio*; (J)* R. sessiliflorus*; (K)* R. glabrifolius*; (L)* R. nanus*; (M)* R. triplodontus*; (N)* R. prasinus*; (O)* R. acaulis*; (P)* R. jugosus*; (Q)* R. gunnianus*; (R)* R. amphitrichus.

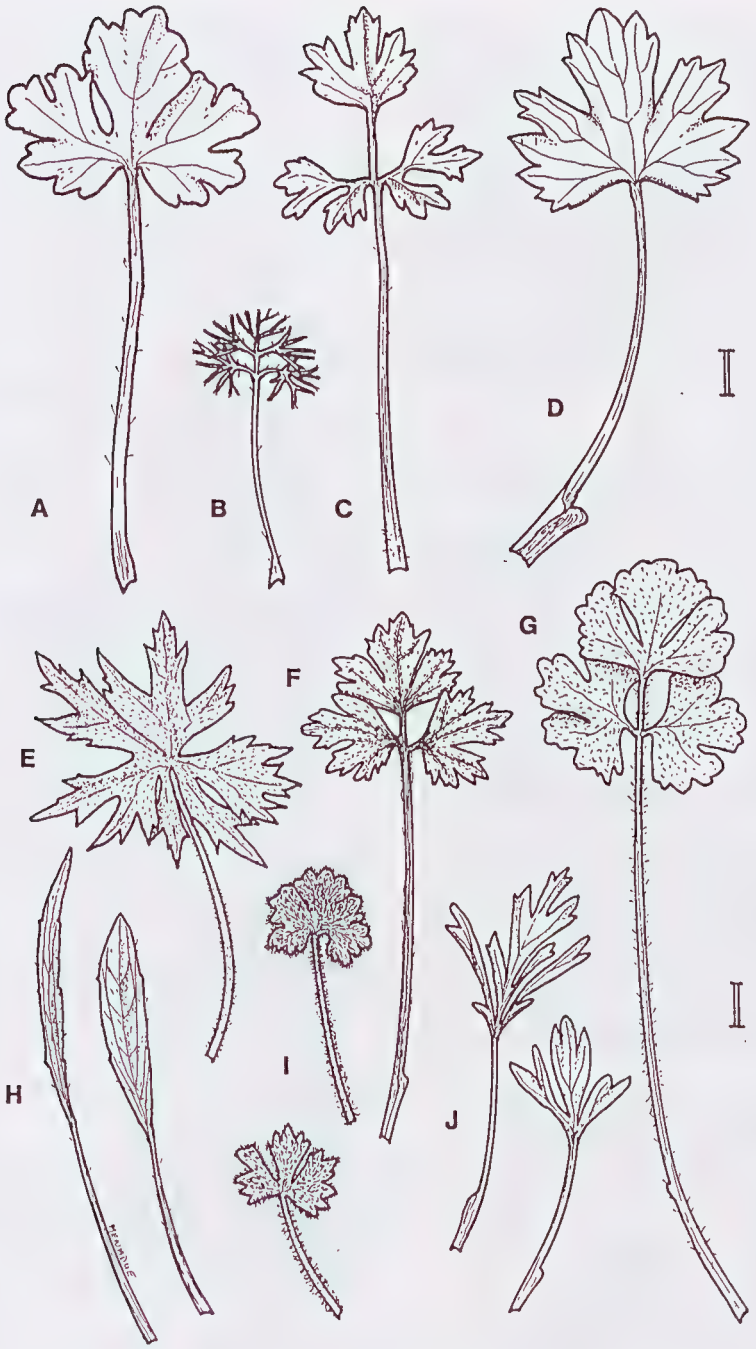

FIG. 2 — Leaves of the introduced and cosmopolitan Ranunculus *species. Scale bar = 1 cm. (A)* R. sceleratus*; (B)* R. trichophyllus *— segments occur in three-dimensions; (C)* R. trilobus*; (D)* R. muricatus*; (E)* R. acris*; (F)* R. repens*; (G)* R. sardous*; (H)* R. flammula*; (I)* R. parviflorus*; (J)* R. arvensis.

Flowers solitary and terminal or in cymose panicles, hermaphrodite, regular. Sepals 3–5. Petals 5–8, rarely fewer (2–3) or more (up to 24); often golden-yellow and glossy (due to a starch layer) except at the base, or pale-yellow or white and matt (starch free). Nectary or nectar-secreting pit on upper surface of petal in lower half, sometimes covered by a thin scale which may be free or adnate to the petal, forming a pocket (figs 4 & 5). Stamens numerous, rarely only five or fewer. Carpels indefinite in number, free with one basal ovule.

Fruit a globular or elongated head of achenes each with a persistent style forming a glabrous beak (fig. 3).

KEY TO *RANUNCULUS* IN TASMANIA

Letters in brackets refer to figure 6. Numbers at right refer to later entries in the Key. Superior numbers after names refer to Notes section which follows.

(1) Aquatic or semi-aquatic plants 2
Terrestrial, swamp or marsh plants 3

(2) Leaves trichotomously dividing into capillary segments in several planes (C) .... *R. trichophyllus* [1]
Leaves palmatifid, palmatisect or ternate, segments in one plane (F,H,I) .... *R. amphitrichus* [2]

(3) Plants connected by long runners or stolons 4
Plants tufted with fibrous roots or with short creeping rootstock 12

(4) Basal leaves in a rosette connected by stout above-ground stolons ... *R. repens* [3]
Basal leaves in a rosette connected by slender underground stolons 5

(5) Leaves palmatifid or palmatisect (H,I) 6
Leaves trifoliolate, ternate or ternately lobed (E,F,G) 7

(6) Sepals appressed hairy; lamina leathery, glabrous or sparsely hairy with teeth apices acute; large (>12 mm), golden-yellow flowers ... ... *R. glabrifolius* [4]
Sepals glabrous; lamina not leathery, glabrous, teeth apices blunt; small (3–13 mm), pale-yellow flowers ... *R. amphitrichus* [2]

(7) Sepals with dense appressed hairs 8
Sepals sparsely villous or glabrous 9

(8) Leaves matt, leathery, teeth apices acute .... *R. glabrifolius* [4]
Leaves glossy, ± fleshy, teeth apices blunt ... *R. collinus* [5]

(9) Leaves villous ... *R. prasinus* [6]
Leaves glabrous 10

(10) Leaf lobes usually dentate, flowers pale greenish-yellow 11
Leaf lobes rarely dentate, 1–3 golden-yellow flowers, 5–8 mm diam. ... *R. collicolus* [7]

(11) Leaflets ± fleshy, torus glabrous in the staminal zone ... *R. acaulis* [8]
Leaflets thin, torus with ring of stiff hairs in the staminal zone ... *R. amphitrichus* [2]

(12) Basal leaves entire, not lobed 13
Basal leaves divided or lobed 15

(13) Leaves cuneate, 3-dentate, lamina truncate at the base ... *R. triplodontus* [9]
Leaves linear, linear-elliptic tapering into a petiole 14

(14) Lamina narrow linear, ± terete, rarely trifurcate (A) ... *R. setaceus* [10]
Lamina linear-elliptic or spathulate (D) .... *R. flammula* [11]

(15) Leaves in a basal rosette, rarely with small cauline leaves or bracts on flowering stems 16
Basal leaves in a rosette, with numerous smaller cauline leaves 24

(16) Leaves with numerous, narrow terete, linear segments (B) ... *R. gunnianus* [12]
Leaves with laminate segments 17

(17) Flowers golden-yellow, conspicuous on scapes as long as or longer than the leaves 18
Flowers pale yellow, inconspicuous on scapes shorter than the leaves 22

(18) Sepals reflexed, leaves mainly palmatifid, softly sericeous hirsute ... *R. scapigerus* [13]
Sepals spreading or appressed to petals 19

(19) Hairs on stems and leaves closely appressed; leaflets attached asymmetrically ... *R. pascuinus* [14]
Hairs on leaves spreading, on stems spreading or appressed; leaflets attached symmetrically 20

(20) Nectary naked, forming a crescentic pit one-third from base of petal; with a short, stout rhizome ... *R. nanus* [15]
Nectary covered by a petaloid or small fleshy lobe or nectary a bracket; without a rhizome 21

(21) Leaves pinnate; nectary lobe rounded, or sub-acute triangular ... *R. pimpinellifolius* [16]
Leaves ternate or ternately lobed; nectary lobe truncate, free to half-attached ... *R. lappaceus* [17]

(22) Leaves pinnate, hirsute; scape elongating above the leaves when in fruit; nectary a crescentic bracket ... *R. decurvus* [18]
Leaves not pinnate, glabrous; scape, often on thick peduncle which bears leaves and may act as an epigeal stolon, elongating in fruit but shorter than the leaves; nectary covered by a small fleshy lobe 23

(23) Leaves ternate, palmatifid or entire-cuneate, glabrous or hairy; petals 0–6 .... *R. triplodontus* [9]
Leaves trifoliolate, lateral leaflets distant from terminal leaflet, glabrous; petals 5–6 .... *R. jugosus* [19]

(24) Achenes smooth 25
Achenes with hairs, spines or tubercles 26

(25) Achenes in oblong head; basal leaves ternately lobed or palmatifid, sparsely hairy ... *R. sceleratus* [20]
Achenes in globular head; basal leaves palmatisect with cuneate segments, pubescent ... *R. acris* [21]

(26) Flowers very small, <7 mm diam.; petals pale-yellow or lemon; sepals erect 27
Flowers >8 mm diam.; petals golden-yellow, sepals reflexed 30

(27) Nectary a prominent petaloid lobe wider than petal; achenes with very long prominent spines ... *R. arvensis* [22]
Nectary a small pocket or bracket, achenes with tubercles or bristles 28

(28) Flowers 4–7 mm diam.; achenes covered with conical tubercles only ... *R. parviflorus* [23]
Flowers 2–3 mm diam.; achenes covered with tubercles ending in a stiff bristle, or bristles only 29

(29) Achenes with numerous bristles over lateral faces and margins ... *R. pumilio* [24]
Achenes with a few conical tubercles ending in recurved bristles over lateral faces but not margins ... *R. sessiliflorus* [25]

(30) Leaves palmatifid; sepals ± glabrous, achenes with smooth margins and long spiny tubercles ... *R. muricatus* [26]
Leaves trifoliolate or ternate; sepals pubescent, achenes with short, blunt tubercles 31

(31) Flower 8–12 mm diam.; stamens 35–50; achenes with flattened brown face and short, blunt conical tubercles ... *R. trilobus* [27]
Flower 12–25 mm diam.; stamens 10–18; achenes with small obtuse tubercles round margin ... *R. sardous* [28]

NOTES ON EACH SPECIES

Chromosome voucher specimens were collected in Tasmania by Menadue and Crowden, unless stated otherwise, and are lodged in the Tasmanian Herbarium (HO).

(1) *R. trichophyllus* Chaix (Cosmopolitan) Figs 2B, 3N, 5G
An aquatic species in farm dams and slow-moving creeks and rivers. The petals distinguish this species from all other Tasmanian species; they are white with a yellow claw (base) and have a nectary which is a naked semi-lunar pit. Chromosome number 2n = 32.
Voucher specimen:
Moscal s.n. Blackman R., 26.xi.1984 (HO88754).

(2) *R. amphitrichus* Colenso (Native) Figs 1R, 3M, 5K. (Synonym: *R. rivularis* Banks & Sol. ex DC.)
A species with widespread distribution in lagoons, creeks and streams from sea level to above 1100 m. The flower is small, pale-yellow, inconspicuous and held well above the leaves on long scapes. It is a polymorphic species with three ploidy levels (see above). Plants in coastal lagoons on the west coast have 2n = 64 and a fairly consistent morphology. A population with 2n = 48 has been found at only one location near Lake Sorell and has a distinctive form. All other specimens from around the State appear to have 2n = 96 but they also show extensive morphological variation. At this stage further investigation of the morphological forms is required before separate taxa can be erected.
Voucher specimens:
2n = 96: Isis R., 29.xi.1983 (HO88313); Osterley Rd, 9.xi.1984 (HO89214); Tiger Rise, Dennistoun Rd, 9.xi.1984 (HO88753); Agnews Marsh Ck, 19.iii.1984 (HO88310); N. end Lake Crescent, 17.xi.1983 (HO88312).
2n = 64: Sundown Pt, West Coast, 7.ii.1983 (HO88311).
2n = 48: Agnews Marsh, 14.xi.1984 (HO91156).

(3) *R. repens* L. (Introduced) Figs 2F, 3S, 5R
A widespread weed of gardens, farms and roadside ditches. Spreads by means of vigorous above-ground stolons and has a conspicuous golden-yellow flower. 2n = 32.
Voucher specimen:
University of Tasmania grounds, Hobart, 14.xi.1984 (HO88755).

(4) *R. glabrifolius* Hook. (Native) Figs 1K, 3K, 5L
A widely distributed species in wet areas from 100–1140 m elevation. Though it may be confused with the following species (*R. collinus*), it has larger, golden-yellow flowers and leaves, and may be distinguished by leaf size, teeth apices which are more acute, and by fruit being borne on erect scapes. Two ploidy levels have been found, 2n = 48 and 64.
Voucher specimens:
2n = 48: Hazelwood Lagoon, 7.xi.1984 (HO89216).
2n = 64: Lake Tiberias Railway Station, 3.xi.1983 (HO88315).

(5) *R. collinus* R.Br. ex DC. (Native) Figs 1H, 3L, 5M
A species which is widespread in montane and sub-alpine regions above 600 m, in wet seepage areas or slow-running creeks. Compared with *R. glabrifolius* it has leaves which are smaller, fleshier and shinier with blunt leaf teeth apices; the golden-yellow flowers are smaller and the fruiting scapes

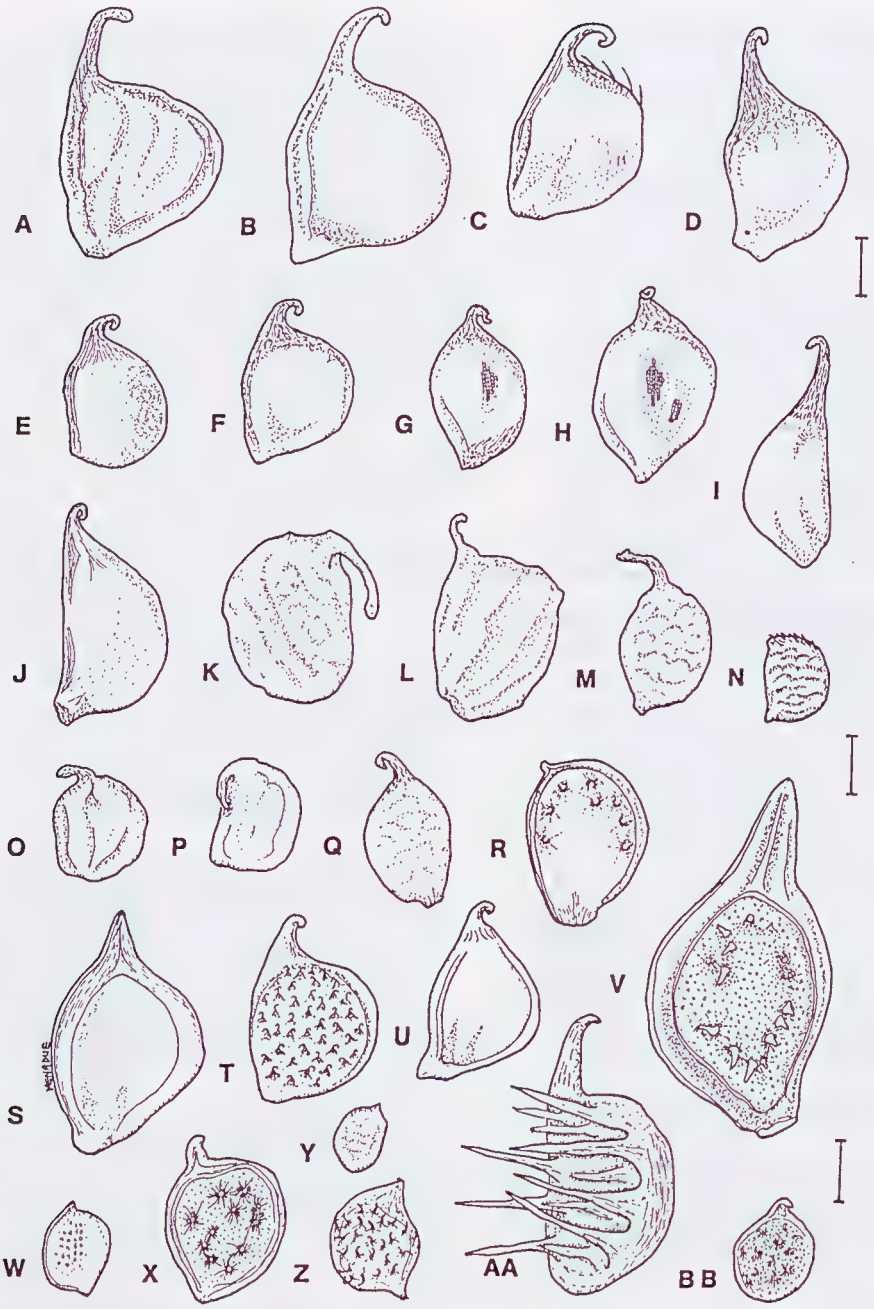

FIG. 3 — Achenes of Tasmanian Ranunculus *species. Scale bar = 1 mm. (A)* R. lappaceus; *(B)* R. pascuinus; *(C)* R. scapigerus; *(D)* R. nanus; *(E)* R. pimpinellifolius; *(F)* R. decurvus; *(G)* R. jugosus; *(H)* R. triplodontus; *(I)* R. gunnianus; *(J)* R. setaceus; *(K)* R. glabrifolius; *(L)* R. collinus; *(M)* R. amphitrichus; *(N)* R. trichophyllus; *(O)* R. acaulis; *(P)* R. prasinus; *(Q)* R. collicolus; *(R)* R. sardous; *(S)* R. repens; *(T)* R. parviflorus; *(U)* R. acris; *(V)* R. muricatus; *(W)* R. flammula; *(X)* R. trilobus; *(Y)* R. sceleratus; *(Z)* R. pumilio; *(AA)* R arvensis ; *(BB)* R. sessiliflorus.

tend to curve over. 2n = 48.
Voucher specimen:
Mt Wellington, 7.xii.1984 (HO88834).

(6) *R. prasinus* Y. Menadue (Endemic) Figs 1N, 3P, 5N
This species shows affinities with *R. collinus* and *R. amphitrichus* but differs by having pale-yellow, glabrous sepals, and thinner grass-green leaflets with acute teeth apices. Its flowers are golden-yellow borne on tall scapes. It is restricted to two small lagoons north of Tunbridge in the Midlands. 2n = 48.
Voucher specimen:
Whites Lagoon, Tunbridge, 11.xii.1984 (HO88842).

(7) *R. collicolus* Y. Menadue (Endemic) Figs 1D, 3Q, 5O
Most closely resembles *R. acaulis* and *R. collinus*; however, it is distinguished by dull, golden-yellow petals with a shallow nectary pocket and mostly entire, narrow leaflets. It is a very small plant about 3 cm high. It is restricted to two small lagoons near Lake Augusta on the Central Plateau. 2n = 48.
Voucher specimen:
Second Lagoon, Central Plateau, 17.ii.1984 (HO88749).

(8) *R. acaulis* Banks & Sol. ex DC. (Native) Figs 1O, 3O, 5B
This grows on consolidated sand near a stream or seepage area in the frontal dunes of sandy beaches on the West Coast. It extends from Ocean Beach near Strahan to Cox Bight in the south. It has a slightly succulent leaf and narrow, greenish-yellow petals. 2n = 48.
Voucher specimen:
Ocean Beach, Strahan, 19.x.1984 (HO88516).

(9) *R. triplodontus* Melville (Endemic) Figs 1M, 3H, 5Q
Widespread in alpine and subalpine grasslands, swamps and creeks. It is very polymorphic in the leaf and has two basic flower forms, 2–3 pale petals or 5 glossier petals. The flowers are inconspicuous and borne on scapes shorter than the leaves. It often may be identified by a stout, potentially stoloniferous stem bearing leaves and flowers at the end. 2n = 48.
Voucher specimens:
Lake Augusta, Central Plateau, 14.xi.1984 (HO88837); Tiger Rise, Dennistoun Rd, 14.xi.1984 (HO88839); Lake Chipman, 17.ii.1984 (HO89211).

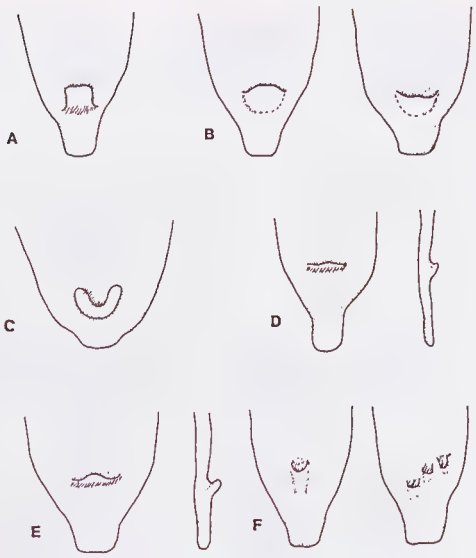

FIG. 4 — Types of nectary in Tasmanian Ranunculus. *(A) a free lobe; (B) a pocket with or without raised lip; (C) a lunate pit; (D) bracket or ledge; (E) bracket or ledge with fleshy lobe; (F) semi-lunar pits or naked glands.*

(10) *R. setaceus* Rodway (Endemic) Figs 1E, 3J, 5I
This grows in small alpine streams or depressions subject to flooding. It will flower and set seed under water. It has a monocotyledonous habit resulting in it often being overlooked. The flower has five pale creamy-yellow petals. 2n = 16.
Voucher specimen:
Ben Lomond Plateau, 19.iii.1984 (HO88306).

(11) *R. flammula* L. (Introduced) Figs 2H, 3W, 5AA
Only known from one farming property *Nabowla* in the northeast of the State. It has a simple leaf blade and a cluster of small, yellow flowers. 2n = 32.
Voucher specimen:
Walker s.n. Nabowla, 14.xi.1984 (HO88873).

(12) *R. gunnianus* Hook. (Native) Figs 1Q, 3I, 5C
This occurs on mountain tops above 1000 m in very wet situations. It is very distinctive with pinnate, linear-lobed, dull-green leaves and very large, golden-yellow flowers with up to 24 petals. The petals have a triple naked nectary which is unique for the Tasmania species. 2n = 48.

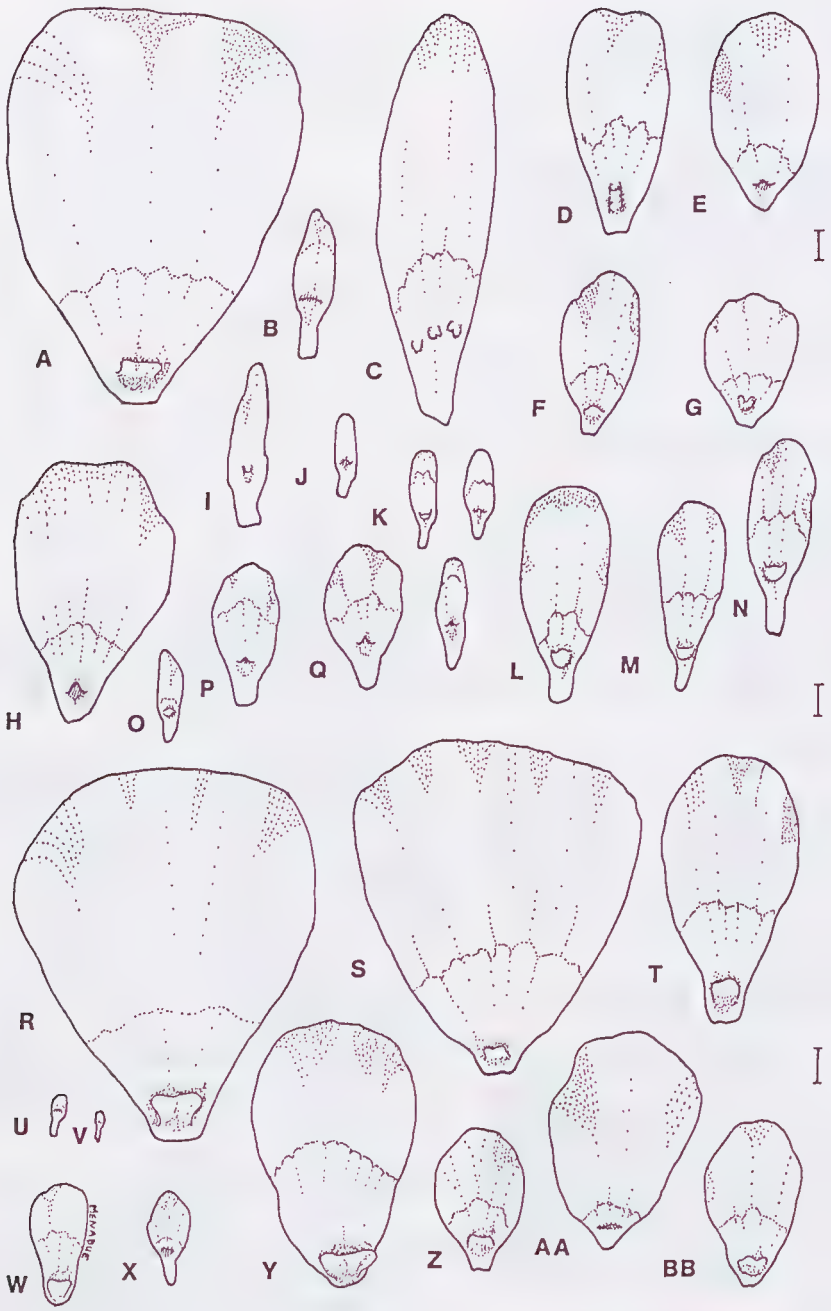

FIG. 5 — Petals of Tasmanian Ranunculus *species showing nectary shape and position. Scale bar = 1 mm. (A)* R. lappaceus; *(B)* R. acaulis; *(C)* R. gunnianus; *(D)* R. nanus; *(E)* R. pimpinellifolius; *(F)* R. scapigerus; *(G)* R. trichophyllus; *(H)* R. pascuinus; *(I)* R. setaceus; *(J)* R. decurvus; *(K)* R. amphitrichus; *(L)* R. glabrifolius; *(M)* R. collinus; *(N)* R. prasinus; *(O)* R. collicolus; *(P)* R. jugosus; *(Q)* R. triplodontus; *(R)* R. repens; *(S)* R. acris; *(T)* R. muricatus; *(U)* R. pumilio; *(V)* R. sessiliflorus; *(W)* R. arvensis; *(X)* R. parviflorus; *(Y)* R. sardous; *(Z)* R. sceleratus; *(AA)* R. flammula; *(BB)* R. trilobus.

Voucher specimen:
Pine Lake, Central Plateau, 11.xii.1984 (HO88835).

(13) *R. scapigerous* Hook. (Native) Figs 1C, 3C, 5F
This grows in wet grasslands and forests often in association with *R. lappaceus*. Its flower is golden-yellow, often red-flushed on a tall scape, and may be distinguished by reflexed sepals. 2n = 16.
Voucher specimen:
Clarence Weir, 11.xii.1984 (HO88845).

(14) *R. pascuinus* (Hook. f.) Melville (Endemic) Figs 1B, 3B, 5H
This occurs in subalpine to alpine habitats on Middlesex Plain and Central Plateau. It has a single golden-yellow flower borne on a tall scape; the plant is covered by appressed hairs and the leaves show a characteristic asymmetry. 2n = 16.
Voucher specimen:
Blackbog Creek, Cradle Mt Rd, 30.xii.1983 (HO88517).

(15) *R. nanus* Hook. (Endemic) Figs 1L, 3D, 5D
Widespread at altitudes of 740–1400 m. This species is vegetatively variable but has a conspicuous golden-yellow flower borne above the leaves. A feature which may help distinguish this species is the frequent presence of a short, thick, erect rhizome which occasionally links two rosettes of leaves. 2n = 16.
Voucher specimen:
Second Lagoon, Central Plateau, 19.iii.1984 (HO88307).

(16) *R. pimpinellifolius* Hook. (Native) Figs 1F, 3E, 5E
This species appears to be restricted to the southeastern part of the Central Plateau and its eastern border. It has a pinnate leaf which may be confused with the leaves of *R. decurvus* (below) but it has a golden-yellow flower borne on a tall scape. 2n = 16.
Voucher specimen:
Clarence Weir, 20.x.1984 (HO88521).

(17) *R. lappaceus* Smith (Native) Figs 1A, 3A, 5A
Widespread and frequent in grasslands and sclerophyll forests with good drainage, often in association with *R. scapigerus*. It has large, golden-yellow flowers on tall scapes, often two per flowering stem. 2n = 16.
Voucher specimen:
Quoin Hill, 16.x.1983 (HO88316).

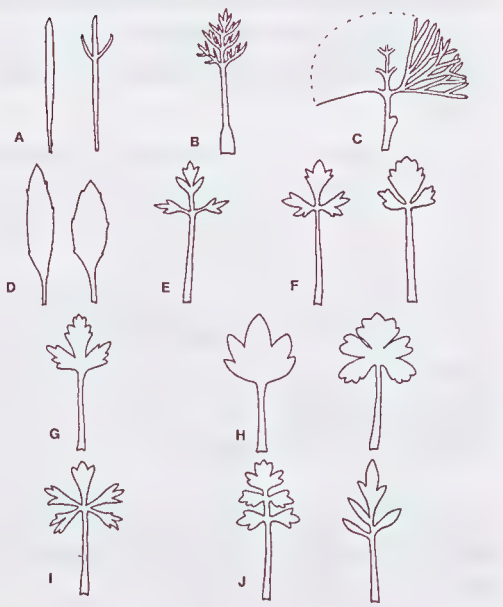

FIG. 6 — Definition of leaf shapes used in the key. (A) Linear ± terete; (B) pinnate with terete segments; (C) trichotomously branching in capillary segments; (D) spathulate, linear lanceolate; (E) trifoliolate, leaflets with distinct petiolules; (F) ternate, in three parts without petiolules; (G) ternately-lobed, in three parts not deeply divided; (H) palmatifid, not deeply divided; (I) palmatisect, deeply divided to the centre; (J) pinnate, (3)–5 leaflets with petiolules.

(18) *R. decurvus* (Hook. f.) Melville (Endemic) Figs 1G, 3F, 5J. (Synonymy: *R. concinnus* (Hook. f.) Melville)
Widespread throughout alpine and subalpine grasslands and heaths above 400 m. It has a small, greenish-yellow flower, borne on a scape much shorter than the leaves, which elongates when fruiting. 2n = 16.
Voucher specimen:
Iris R., Cradle Mt Rd, 29.xi.1984 (HO88309).

(19) *R. jugosus* Y. Menadue (Endemic) Figs 1P, 3G, 5P
Locally abundant in river silt and soak areas of the Central Plateau at altitudes about 1100 m. It is closely related to *R. triplodontus*; however, it has a consistent leaf-form and a flower with six petals. The leaves are pinnately trifoliolate with reflexed

lateral leaflets. They are glabrous and have long, reddish-brown, recurved petioles. 2n = 48.
Voucher specimen:
Lake Augusta, Central Plateau, 10.xi.1983 (HO81877).

(20) *R. sceleratus* L. (Introduced) Figs 2A, 3Y, 5Z
Probably no longer exists in the State. Only one specimen, collected in the early 1900's near Hobart, exists in the Tasmanian Herbarium. This species has an elongated fruiting head.

(21) *R. acris* L. (Introduced) Figs 2E, 3U, 5S
Has been found in agricultural land south of Hobart. The flowering stems can be up to 1 m tall and bear several golden-yellow flowers. 2n = 14.
Voucher specimen:
Kettering, 7.xi.1984 (HO88520).

(22) *R. arvensis* L. (Introduced) Figs 2J, 3AA, 5W
Probably no longer exists in the State. The Tasmanian Herbarium has only one specimen of this species collected at Cressy.

(23) *R. parviflorus* L. (Introduced) Figs 2I, 3T, 5X
A robust weed of waste land. This is a very hairy plant and has numerous small, yellow flowers. The achenes have brownish faces covered with conical tubercles ending in a fine hair. 2n = 28.
Voucher specimen:
Geilston Bay, 18.xi.1984 (HO88752).

(24) *R. pumilio* R.Br. ex DC. (Native) Figs 1I, 3Z, 5U
This appears to be confined to the Midlands regions and mainly grows in pasture grasses in very damp places. The leaves are light grass-green and small, pale-yellow flowers are borne on the stems. 2n = 14.
Voucher specimen:
Brownwater Lagoon, Lake Crescent, 14.xi.1984 (HO88518).

(25) *R. sessiliflorus* R.Br. ex DC. (Native) Figs 1J, 3BB, 5V
This grows in poor rocky soils under dry sclerophyll forest. It is probably more widespread than collections would indicate as it is a straggly inconspicuous plant. 2n = 14.

This species may be separated from *R. pumilio* by the achenes: *R. sessiliflorus* has fewer bristles on prominent, conical tubercles on the surface of the achene, which has a conspicuous margin.

R. pumilio has numerous longer, recurved bristles all over the achene surface, including the poorly defined margin (fig. 3).
Voucher specimen:
Geilston Bay, 14.xi.1984 (HO88840).

(26) *R. muricatus* L. (Introduced) Figs 2D, 3V, 5T
A weed of waste ground and cultivated areas in damp soil. The flowering stems bear numerous golden-yellow flowers with reflexed sepals. The achenes are in large heads and bear a few short spiny tubercles on their surfaces. 2n = 64.
Voucher specimen:
Hamilton, 24.x.1984 (HO88522).

(27) R. trilobus Desf. (Introduced) Figs 2C, 3X, 5BB
Mainly found in the upper Derwent Valley around Glenora and Bushy Park in damp roadside ditches. Flowering stems bear numerous small, golden-yellow flowers with reflexed sepals. The achene has brown faces with blunt conical tubercles and a distinct margin. 2n = 48.
Voucher specimen:
Morris s.n. Glenora, 24.x.1984 (HO88519).

(28) *R. sardous* Crantz (Introduced) Figs 2G, 3R, 5Y
Grows on old agricultural land around the north-west of the State. It has pale-yellow flowers with reflexed sepals. The petals have a large, free-lobed nectary right at the base of the claw. 2n = 48.
Voucher specimen:
Omeo Rd, Victoria, 27.i.1984 (HO88750).

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REFERENCES

Curtis, W.M. & Morris, D.I., 1975: *A STUDENT'S FLORA OF TASMANIA*. Vol.I, 2nd edition. Government Printer, Hobart.

Menadue, Y., 1986: Taxonomy of *Ranunculus* in Tasmania. Unpubl. Ph.D. thesis, Univ. Tasm., Hobart.

Menadue, Y. & Crowden, R.K., 1985: Three new species of *Ranunculus* (Ranunculaceae) from Tasmania. *Brunonia* 8: 373–380.

Menadue, Y. & Crowden, R.K., 1988: Multivariate analysis of variation in *Ranunculus decurvus* (Hook. f.) Melville and *Ranunculus concinnus* (Hook. f.) Melville, Ranunculaceae. *Bot. J. Linn. Soc.* 98(1): 71–83.

(accepted 12 May 1989)

A REVIEW OF PAST AND PRESENT INSHORE GILL NETTING IN TASMANIA WITH PARTICULAR REFERENCE TO THE BASTARD TRUMPETER *LATRIDOPSIS FORSTERI* CASTELNAU

by D. N. Harries and R. L. Croome

(with six text-figures)

HARRIES, D.N. & CROOME, R.L., 1989 (31:x): A review of past and present inshore gill netting in Tasmania with particular reference to the Bastard trumpeter *Latridopsis forsteri* Castelnau. *Pap. Proc. R. Soc. Tasm.* 123: 97–110. ISSN 0080–4703. Centre for Environmental Studies, Department of Geography and Environmental Studies, University of Tasmania, G.P.O. Box 252C, Hobart, Australia 7001.

The evolution of regulatory control of inshore gill netting in Tasmania is documented and compared with that of the mainland Australian States; the historical catch records of one fish in particular, the bastard trumpeter (*Latridopsis forsteri* Castelnau), are used to discuss the appropriateness of past and present management of the Tasmanian inshore scale fishery.

The need for regulation of inshore gill netting first became apparent in the late 1870's; limited control measures were introduced in Tasmania in 1890, primarily to protect juvenile and adult breeding stocks of salmonids. The regulations have been altered little since that time and, at present, lag behind those of the mainland States. Declines in the recorded commercial catch of the bastard trumpeter occurred in the late 1870's and early 1880's and again between 1910 and 1918; more recently a general decline has been shown from the mid-1950's to the present. These declines are discussed in relation to inshore gill netting effort and regulatory control of gill netting in Tasmania, and to the known biology of this species.

Key Words: gill netting, trumpeter, fishery regulation, Tasmania.

INTRODUCTION

A gill net is a curtain of mesh material, weighted at the bottom and attached to floats at the top, and set in a straight line or curve to snare fish which swim into it. Such nets, known colloquially as "graballs", were introduced into Tasmania soon after European settlement in 1803, and gill netting remained the predominant method by which scale fish were taken in Tasmania for over a century. Although it is still commonly practised, little has been written on the subject of inshore gill netting in Tasmania. A netting survey of the Derwent estuary (Dix 1974) and a more recent study of the comparative short-term effects of varied netting pressures on reef fish communities (Schaap and Green 1988) have been the only reports on gill netting published by Tasmanian fisheries authorities to date. The question of the long-term impact of this fishing method on the fish populations concerned remains largely unexamined.

The bastard trumpeter is of particular importance in any study of gill netting in Tasmanian waters, as this species is reputed to be the prime target of Tasmanian non-commercial gill netters (Edgar *et al.* 1982) and is most frequently recorded as captured (although not in the greatest quantities) in the gill nets of commercial fishermen (Tasmania, Parliament 1982). Furthermore, a recent report on the biology of the bastard trumpeter (Harries & Lake 1985) found the entire inshore population of this species to be immature. The possible biological and commercial implications of basing a fishery on a purely juvenile stock are sufficiently serious to warrant further investigation.

The present study traces the evolution of gill netting regulation in Tasmania and compares it with that in other Australian States. Information on the past and present Tasmanian catch of bastard trumpeter is then examined, in order to determine whether there is any evidence of a long-term decline in the catch and, if so, whether this may be attributed to the effects of gill netting.

THE EVOLUTION OF INSHORE GILL NETTING REGULATION IN TASMANIA

Scale fishing in the Australian colonies focussed almost exclusively on inshore bays and estuaries

until well into the 20th century (Stead 1910, Pownall 1979, Lenanton 1979, Winstanley 1985). The early Tasmanian inshore scale fishery, however, was overshadowed in importance by the more lucrative fishing industries of sealing (Murray 1927, Vivian 1983) and whaling (Crowther 1920, Murray 1927, Nicol 1986); also, after the mid-19th century, by oyster dredging (Sumner 1972), crayfishing (Winstanley 1973) and, more importantly, the incipient inland fishing industry (Tasmania, Parliament 1860, 1889a; Allport 1870). The latter, particularly, dominated the attention of the authorities, and a body, the "Salmon Commissioners", was set up in October 1861 to preside over attempts to establish an inland fishing industry based on exotic salmon. Six years later, Tasmania became the first community in the Southern Hemisphere to establish a freshwater fishery based on an introduced species (Tasmania, Parliament 1889).

The early Tasmanian inshore scale fishery operated within the umbra of these more valued industries and received little attention from the colonial authorities; indeed, apart from an Act introduced in 1870 to prohibit the sale or purchase of flounder under 9 in. (230 mm) in length (34 Vict. No. 24), it operated without regulation for the greater part of the 19th century. The consequences of this lack of control became apparent in the late 1870's, when concern over declining catches of many of the colony's commercially important marine fishes culminated in the establishment of a Royal Commission into Tasmanian Fisheries in 1881.

The timing of this Royal Commission was also stimulated by events occurring in the other Australian colonies. Although Victoria and New South Wales had passed their first Fisheries Acts in 1863 and 1865 respectively, no other Australian colony had moved to introduce similar legislation prior to the 1880's. Further declines in fish catches from the estuarine and inshore waters of New South Wales led the Government of that colony to hold a Royal Commission into the matter in 1880 and, subsequently, to introduce a second and more encompassing Fisheries Act in 1881. The enactment of this legislation appears to have been the cue for the more peripheral Australian colonies to introduce the rudiments of regulations for governing their own fisheries, and, by 1889, all the Australian colonies had introduced fisheries-related legislation.

The Report of the Royal Commission into the Fisheries of Tasmania (Tasmania, Parliament 1882) attributed the marked decline in catches to uncontrolled inshore netting activity and advised (p. xiii) that

> "the necessity for more effective protection to indigenous fishes is most apparent in reference to flounders, mullet, bastard trumpeter, and perch because these fish are destroyed in such large numbers in an immature state."

This report proposed the adoption of a number of mechanisms utilised in the extant Victorian and New South Wales fisheries regulations, viz. the reservation of nursery grounds "wherein the seine and other objectionable nets shall be absolutely prohibited" (p. xiv); the outlawing of the practice of drawing seine nets ashore before they were emptied and sorted; the temporary closures of exhausted grounds; a total prohibition of fixed nets across river mouths or channels and the introduction of a regulation limiting the minimum mesh size of graballs to 4 in. (100 mm). The Royal Commissioners acknowledged, however, that the paucity of information on the breeding habits and nursery grounds of many of the colony's marine fishes militated against the introduction of specific protective measures for these; furthermore, they were of the opinion that breeding stocks of "such fish as the silver bastard, trumpeter, and perch" were naturally protected in deeper and more remote waters.

The report concluded its recommendations with a call for the creation of a single Board responsible for both the inland and the sea fisheries of the colony, and for the appointment of a skilled inspector to carry out the Regulations as fixed by that Board. Eager to have at their disposal a skilled adviser with European experience, the Salmon Commissioners quickly endorsed the latter of these recommendations and prevailed on the Chief Secretary of the Colony to invite its long-time adviser on salmon cultivation, Sir Thomas Brady, Chief Inspector of Irish Fisheries, to select a suitable person. On the recommendation of Professor Huxley of the Royal Society in London, an experienced biologist, Mr W. Saville-Kent, was offered the position.

Saville-Kent arrived in Hobart from London on 18 July 1884, and his reports to Parliament over the following years (Tasmania, Parliament 1884, 1885, 1887) give testimony to the energy and enthusiasm with which he launched himself into his new position as Superintendent and Inspector of Fisheries of the colony. After surveying the condition of the colony's once-famous oyster grounds and discovering these to be severely depleted, he initiated a programme of oyster cultivation

involving the construction of artificial oyster beds. He brought with him a view that the study and cultivation of indigenous marine species was of paramount importance, and orchestrated the construction of a marine laboratory and hatchery. He drafted a Bill aimed at regulating the southern rock lobster (*Jasus novaehollandiae* Holthius) fishery, which was passed by Parliament in 1885 (49° Vict. No.27). Nor did he overlook the freshwater fishery, arranging for the cultivation of indigenous freshwater species to augment the established exotic salmon and trout breeding-programme. In short, the scientific study and management of the sea fisheries of Tasmania were lifted out of the doldrums of the past era of neglect and set on a course which threw down the gauntlet to the other Australian colonies.

Saville-Kent's activities, while impressive, were also the cause of considerable perturbation to the members of the Salmon Commissioners (Tasmania, Parliament 1886). His assumed independence from their authority and his concentration on marine and indigenous freshwater species, rather than on the salmon and trout fisheries, were regarded as a perversion of the original intent behind his appointment and a provocative challenge to their previously unquestioned status as the sole fisheries authority in the colony. The Commissioners looked to the Government to rectify what they perceived as a temporary, but grossly annoying situation by clarifying their statutory status and authority. Much to their chagrin, however, the Fisheries Inspection Act (48° Vict. No.23), introduced in October 1884, clearly placed the newly-appointed Superintendent and Inspector of Fisheries under the direct control of the Chief Secretary rather than the Salmon Commissioners. Indignant, they embarked upon a protracted campaign to have the second recommendation of the 1881 Royal Commission adopted and the administration of the inland and sea fisheries of the colony reorganised under a single Board, with Saville-Kent demoted to a position of Inspector under the control of this Board. Capitulating to this pressure, the Government sought a compromise and, in 1887, established a Fisheries Department, consisting of a Fisheries Board (23 appointed members responsible for both the inland and the sea fisheries, with the exception of the oyster fishery) and a Superintendent and Inspector of Fisheries (responsible solely for the oyster fishery).

Saville-Kent remained as Superintendent and Inspector of Fisheries with responsibility for the oyster fishery, but spent only two months of the year in Tasmania carrying out these duties, the remaining months being employed in the capacity of fisheries adviser to the mainland colonies. The dispute did not end there, however, and became embittered when Sir Thomas Brady, on a visit to Tasmania, elected to enter the fray by submitting to Parliament, at the request of the newly appointed Fisheries Board, a report on the fisheries of Tasmania which was openly critical of the management of the colony's oyster fishery (Tasmania, Parliament 1888/1889a). After an embittered and public exchange of correspondence on the matter, Saville-Kent resigned as Superintendent and Inspector of Fisheries; his laboratory and hatchery were dismantled and research into the colony's sea fisheries extinguished.

One of the first tasks of the newly-created Fisheries Board was to address the pressing question of netting in the Derwent estuary, amidst conflict between anglers and net fishermen and claims by both parties that fish catches in these waters were continuing to fall. A Committee of Inquiry was established in 1888 and called on Sir Thomas Brady to assist. Sir Thomas returned written replies to all of the Committee's set questions and also submitted a report on the fisheries of Tasmania to the Committee (Tasmania, Parliament 1888/1889b) and to Parliament (Tasmania, Parliament 1888/1889c). At the request of the Committee, Sir Thomas drafted a comprehensive Fisheries Bill, amending and consolidating the existing laws. This was presented to Parliament late in 1888 and on 28 October of the following year the *Fisheries Act* 1889 (53° Vict. No.11) became law.

Under the new Act, the short-lived Fisheries Board was replaced by a new authority, the "Commissioners of Fisheries", consisting of 25 honorary members. The Fisheries Regulations gazetted in 1890 introduced minimum sizes at which fish could be captured for a small number of species; in the case of bastard trumpeter this minimum length was set at 12 in. (305 mm). The absence of biological data upon which to select appropriate minimum lengths, other than the general observations published by Johnston (1882, 1890), meant that these sizes were largely subjective.

These regulations also introduced limited control of gill netting activity in Tasmania for the first time. A minimum mesh size of 2.25 in. (58 mm) was set for graballs, although no limits were imposed on the number of nets which could be used and, unlike contemporary regulations introduced by most of the other Australian colonies, there was no requirement for licensing of either commercial or

amateur nets. The regulations did require commercial fishermen to take out annual commercial fishing licenses, but this was rendered ineffectual as no power was vested in the Commissioners of Fisheries to enforce the payment of licence fees. No limits were set on the maximum lengths of gill nets until 1893, when the regulations were amended to limit the length of gill nets used in Tasmanian coastal waters to 80 fathoms (240 yds — 220 m) and the depth to a maximum of 15 ft (4.6 m). Length and depth restrictions on gill nets were subsequently rescinded with the gazettal of the Fisheries Regulations of 1905.

Economic depression had led the Government to withdraw funding for Fisheries in the 1890's and the "Commissioners of Fisheries" thereafter relied solely on licence fees to fund its activities. Thus starved of funds and administered by honorary Commissioners appointed largely on the basis of their interest in freshwater angling, without the time or practical knowledge with which to properly manage the sea fisheries of the State, the industry languished and dissatisfaction grew in the post-federation years. Calls for a divorce of the administration of the inland and sea fisheries (Tasmania, Parliament 1913, 1916/17) eventually forced the Government to introduce the *Fisheries Act* 1925, under which the Sea Fisheries Board, consisting of five appointees and chaired by the Commissioner of Police (*ex officio*), was established. Although Professor T. Flynn, of the University of Tasmania, was appointed as Scientific Adviser to this Board, the Government was criticised by the Secretary of the Royal Society of Tasmania, Mr L. Rodway, for failing to include on the Board any representative with a scientific knowledge of the sea fisheries (Tasmania, Attorney General's Department 1928).

The additions to the fishing regulations which accompanied the administrative changes in this Act were relatively minor: the anomaly which had previously allowed commercial fishermen to avoid playing commercial fishing licence fees was rectified; further closures of rivers and estuaries to netting were introduced, in almost all cases, for the protection of trout stocks; the minimum size at which bastard trumpeter could be taken was increased from 12 to 13 in. (305 to 330 mm), although the reason for this action could not be determined by the present authors. Thirteen years later (1938), the minimum mesh size of graballs was increased from 2.25 to 3 in. (58–76 mm). The change was rendered somewhat technical, however, as these same regulations defined for the first time a "mullet net" with a minimum mesh size of 2 in. (51 mm). No maximum lengths or depths were prescribed for either graballs or mullet nets at this time.

Accusations of impropriety led, in 1940, to the establishment of an Inquiry into the effects of trawling in the Derwent estuary and the D'Entrecastreaux Channel. Commercial fishermen used the opportunity to vent their grievances concerning what they perceived to be unfair competition from amateur net fishermen (Tasmania, Attorney General's Department 1940). Many commercial fishermen lobbied to have amateur gill netting totally prohibited. However, the Secretary of the Sea Fisheries Board, Edwin Percy Andrewartha, argued against such a prohibition on the grounds that the fish in the sea were the "property of the people" (*ibid.*:147) and that netting by amateur fishermen represented a traditional right. Although recommending that Tasmania follow the example of the mainland States by introducing regulations requiring licensing of both amateur and commercial nets, the report of the Board of Inquiry was never released and its recommendations were never acted upon.

In 1941, the Sea Fisheries Board was abolished and replaced by a Fisheries Division within the Department of Agriculture, administered by a Sea Fisheries Advisory Board, and for the first time the sea fisheries of the State came under full ministerial control. At its inaugural meeting on 25 September of that year, the Board elected to revise the existing regulations (Tasmania, Sea Fisheries Advisory Board 1941). Due to the intervention of World War II, however, membership of the Board lapsed after 1942, and only after reactivation of the Board in 1947 was a revision of the sea fisheries regulations again considered (Tasmania, Sea Fisheries Advisory Board 1947). Under the amended regulations, gazetted in 1950, the minimum size at which bastard trumpeter could be taken was reduced from 13 in. (330 mm) to the pre-1926 limit of 12 in. (305 mm) and the minimum mesh size of gill nets was raised from 3 to 4 in. (76 to 100 mm). An examination of the minutes of the Sea Fisheries Advisory Board meetings held between 1941 and 1950 failed to disclose the reason for these changes. It is likely, however, given the lack of biological research carried out at this time, that the changes were implemented for administrative rather than biological reasons.

Amendments to the regulations during this period coincided with the introduction of new synthetic materials from which nets were constructed. Regulation of gill netting in Victoria, New South

Wales and the Northern Territory also underwent significant change during this period. In 1950, the New South Wales Government placed a total ban on the use of these nets by amateur fishers, introduced further restrictions on the maximum lengths and minimum mesh sizes of commercial gill nets, and significantly increased the area of inshore waters closed to netting. The Northern Territory Administration introduced a total ban on amateur gill netting and a prohibition on commercial gill netting within two nautical miles (3.7 km) of the coast in the early 1950's. The Victorian Government also moved to totally ban amateur gill netting during this period, and by the 1960's gill netting by amateurs remained legal in only three of the Australian States: South, Australia, Western Australia, and Tasmania (Queensland had outlawed the use of gill nets by amateurs with the introduction of its first Fisheries Act in 1887).

In Tasmania, regulations pertaining to the use of gill nets for amateur fishing differed from those pertaining to their commercial use for the first time in 1966, when a maximum length for graballs and mullet nets used by amateurs was set at 75 yards (68 m). Under these same regulations, amateurs were also restricted to using a maximum of two graballs at a time. Changes to licensing of the sea fisheries came about with the introduction of the 1968 Fisheries Act; these would have required the licensing of amateur net fishing, had it not been for the action of the Legislative Council, which successfully moved to exempt amateurs from the provisions of the Act. In 1974, a maximum of two mullet nets per amateur fisherman was imposed. In that same year, net specifications were metricated and the maximum length of graballs used by amateurs was further reduced to 50 m. An apparent oversight omitted any limit on the maximum length of mullet nets; this was not rectified until 1984 when a maximum length of 50 m was set for these nets also. Minimum mesh sizes remained almost unchanged for both graballs (100 mm) and mullet nets (60 mm).

Further administrative changes in the sea fisheries were implemented after publication of a Government-commissioned study of the industry (O'Kelly 1976). A Fisheries Development Authority was established in 1977. This Authority, however, survived only nine years and was replaced in February 1985 by a Sea Fisheries Department.

Biological research into the sea fisheries of Tasmania had ended abruptly with the departure of Saville-Kent in 1887. Although successive scientific advisers had been included on the Sea Fisheries Board since its inception in 1925, these scientists had not been actively engaged in research programmes into sea fisheries. A professional fisherman turned policeman, Mr Tom Challenger, was placed in charge of policing the fisheries regulations in 1916 and continued in this capacity until 1945, when he resigned from the Police Department to take up the position of Fisheries Inspector. He remained as Chief Fisheries Inspector until his resignation in 1950. It was largely to this person that the Sea Fisheries Board, and later the Sea Fisheries Advisory Board, turned when seeking advice on the necessity for changes to the regulations. During the 1940's, scientists from the CSIRO acted as advisers to the Sea Fisheries Advisory Board, but it was not until the appointment of Mr M. Hodgson in 1950 that a marine biologist was engaged by the Sea Fisheries Division to conduct research. This attempt to initiate biological research into the sea fisheries, however, proved to be premature and soon failed, due to the absence of suitable facilities (Tasmania, Sea Fisheries Advisory Board 1958). Not until 1968, some 80 years after the departure of Saville-Kent from Tasmania, were such facilities provided. In that year, construction began on the marine laboratories at Crayfish Point, marking the start of a new era in the management of the sea fisheries of Tasmania in which research would increasingly play a part. For the inshore scale fishery, however, this change had unfortunately arrived too late. Significant developments in the rock lobster (Winstanley 1973), scallop (Perrin & Hay 1987), and abalone (Harrison 1982) industries had eclipsed the inshore scale fishery and ensured that almost no research effort was focussed on it.

Regulations governing the use of graballs and mullet nets have remained almost totally unchanged since first introduced in the 1890's and are today the most lenient in Australia. There are no restrictions limiting the lengths or numbers of nets which commercial fishermen may employ and no requirements for licensing of either amateur or commercial nets. Although netting is prohibited in most coastal lagoons and rivers of the State, only one small coastal aquatic reserve (64 ha. located in the Derwent estuary adjacent to the marine laboratories at Crayfish Point) has been declared in Tasmania to date. Netting in this reserve is allowed during daylight hours.

Past regulatory control of the inshore scale fishery in Tasmania has paralleled most closely that of Western Australia and of South Australia. These three States have shared a history of lenient

legislation pertaining to gill netting and remain the only States in which gill netting by amateurs is not totally prohibited. In both Western Australia and South Australia, however, inshore netting has been a contentious issue and major changes have been implemented in both of these States over the past decade and a half. In South Australia, biological studies and surveys of fishing pressure have led to extensive reviews of netting regulations (Jones 1979, 1981, 1986; MacDonald 1986). Large numbers of coastal areas of that State have now been totally closed to netting, the number of commercial licences has been reduced and the number of amateur licenses frozen. Limits have also been placed on the time for which amateurs may set a net and they are required to remain on site while their net is in the water.

In the case of Western Australia, extensive reviews of controls over inshore netting in recent years (Lenanton 1979, 1984) have not led to the implementation of controls to the same extent, and regulations governing the use of nets for commercial and amateur fishing in that State remain relatively lenient. However, 62 coastal areas have been totally closed to netting to date, including almost all waters within an 80 km radius of the capital city, Perth. The retention of more lenient regulation in many of Western Australia's more peripheral coastal inshore waters has been possible through the extensive nature of the Western Australian coastline and the large distance of many of the inshore waters from population centres.

With these measures being taken by South Australia and Western Australia, Tasmania now lags behind the other Australian States in the regulation of netting in its inshore waters. Since measures to control gill netting were first introduced in 1890, changes to the regulations have been slow and marginal. Only recently has research into the effect of this minimal regulation of netting on inshore populations of the various fish species been initiated, and the question has yet to be sufficiently addressed. In the following section, catch records of one fish, the bastard trumpeter, are examined in order to obtain some insight into the effect of gill netting on inshore species.

PAST TRENDS IN THE COMMERCIAL CATCH OF BASTARD TRUMPETER

The first records relating to the catch of the bastard trumpeter (*Latridopsis forsteri*) in Tasmanian waters are the anecdotal accounts presented to the first Royal Commission into the Fisheries of Tasmania in 1881 (Tasmania, Parliament 1882). Evidence presented to this inquiry indicates that local fishermen considered unchecked inshore netting to be at the root of observed declines in the annual catches of bastard trumpeter and other inshore fishes.

After the turn of the century, records kept of the numbers of each species of fish sold through the Hobart Fish Market, published in the Annual Reports of the Commissioners of Fisheries, represented the only information to which the authorities could turn to obtain a picture of the trends occurring in the sea fishery. Although aware that these figures were, at best, crude indicators of the true annual catch, the Commissioners considered the records to give "a fair idea of the relative trend of the supply of fish and their wholesale prices" (Tasmania, Parliament 1919/1920).

The numbers of bastard trumpeter recorded as sold through the Hobart Fish Market each year for the period 1910 to 1923 are shown in figure 1. There was a considerable decline in the number sold each year between 1910 and 1918, particularly after 1915, and, although sales improved after 1918, the number sold in the final year of the period (1923) was less then one-third of the number sold in 1910. At first sight, it would appear as if this decline were related in some way to the onset

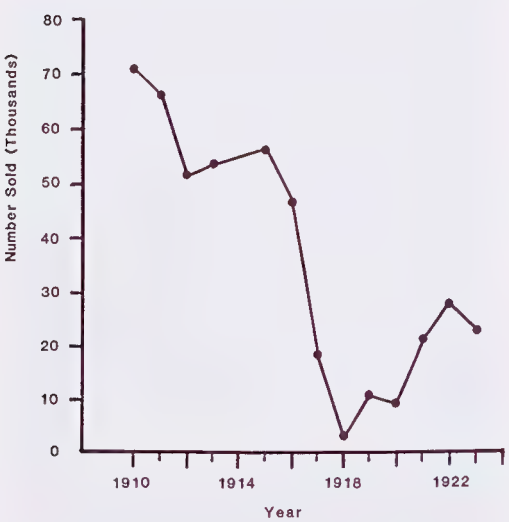

FIG. 1 — Numbers of bastard trumpeter sold through the Hobart Fish Market, 1910–23.

of the Great War (1914–18). The Fisheries Commissioners, however, did not consider the overlap of these two events to be linked and found themselves at a loss to account for the state of affairs (Tasmania, Parliament 1919/1920), particularly as boats of an improved class and in greater numbers were operating (Tasmania, Parliament 1916/1917).

The prices of all fish species escalated dramatically over this period, giving rise to a second Royal Commission into the fisheries of the State (Tasmania, Parliament 1916/1917). The price increases of bastard trumpeter outstripped those of all other fish, suggesting that this species had become comparatively scarce. The downward trend in the annual commercial catch of bastard trumpeter (fig. 1) was paralleled by all other fish species sold through the Hobart Fish Market during this period. Together these facts led the Commissioners to report that "the most prolific grounds have ceased to yield the usual harvest" (Tasmania, Parliament 1920/1921). The decline in the annual commercial catch of bastard trumpeter appears to have resulted from the severe reduction of stocks in estuarine and inshore waters.

From 1924 to 1940, the police were employed to collect statistics of fish catches from local fishermen. Although recognised as subject to many flaws, largely "due to the disinclination on the part of many fishermen to keep accurate records of fish captured for the market" (Tasmania, Sea Fisheries Board 1933), the figures were regarded as "substantially correct" (Tasmania, Attorney General's Department 1940). The numbers of bastard trumpeter reported as captured during this period generally fluctuated between 60 000 and 80 000 per annum, except in 1932 and 1939 when the reported catches were 173 844 and 169 620 respectively (Tasmania, Sea Fisheries Board 1930, 1933, 1940). Bastard trumpeter comprised, on average, approximately 6% of the total annual catch (by numbers) throughout this period.

Maintenance of a relatively high catch was made possible, according to the secretary of the Sea Fisheries Board, by "intensive fishing of the home (sheltered inshore) and middle (exposed inshore) grounds" (Tasmania, Attorney General's Department 1940). Gill netting of the inshore waters had extended to the more remote estuaries and bays of the State by 1930, including some fishing on the west and southwestern coasts (Kerr 1985), and it would appear that these virgin grounds sustained the relatively large annual catch of bastard trumpeter during the period.

Fishing activity in Tasmania was disrupted by the war effort between 1940 and 1944 and publication of annual catch data was limited. After 1944 a more accurate system of fish catch statistics was introduced, whereby fishermen were issued with log books and obliged to keep accurate records of monthly catches for each species. The data collected from these fishing returns provided reasonably accurate estimates of fish catches, although information collected for species such as the bastard trumpeter, which were of lesser commercial importance and were taken as part of a composite catch, is likely to have been less reliable.

Information compiled from these fishing returns was published in the Annual Reports of the Department of Agriculture up to 1961, and thereafter by the Australian Bureau of Statistics (ABS) in the annual publication, the Yearbook of Tasmania. In 1977, the ABS ceased to rely on figures obtained from fishing returns and used instead the weight of each type of fish purchased by fish buyers from fishermen. A weakness of this published information, from the point of view of the present study, was that the annual catch of the bastard trumpeter was usually pooled together with that of the striped trumpeter (*Latris lineata* Bloch & Schneider) and presented as the "trumpeter" catch. However, the Department of Agriculture published the annual catch of the two trumpeter species separately from 1966/67 to 1971/72, and bastard trumpeter constituted the major component of the "trumpeter" catch each year of this period (see fig. 2), confirming the persistent view within the literature that the landed catch of striped trumpeter has been consistently smaller than that of the bastard trumpeter. The "trumpeter" catch for period 1944/45 to 1985/86 is plotted in figure 2.

The reported annual commercial catch of trumpeter has shown a general decline since 1952. The catch was around 45 tonnes per annum from 1944/45 to 1948/49, then fluctuated, with a peak of 52 tonnes in 1952, stabilised at 30–35 tonnes for the period 1954–60, fell to a low of one tonne in 1976/77, and then improved somewhat to around 6–12 tonnes per annum after 1980. The question is whether this general decline in the reported catch was due to a decline in the abundance of the bastard trumpeter or a reduction in gill netting effort, or was a result of commercial fishermen failing to report catches of this fish.

In 1939, there were approximately 190 fishing boats engaged in scale fishing in Tasmania (Tasmania, Attorney General's Department 1940). In the southern and southeastern regions of the State, only 40 boats were engaged exclusively in scale fishing, ten of them mere dinghies, and

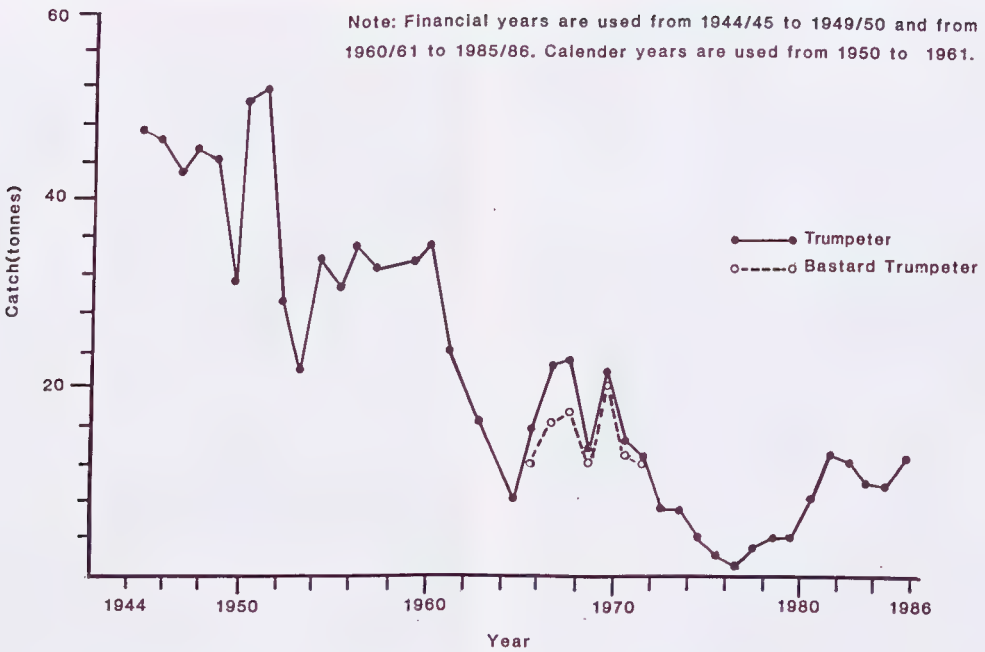

FIG. 2 — Weight of trumpeter landed for sale in Tasmania, 1944–85/86.

documented accounts of sea fishing in Tasmania at that time indicated that only two of these boats worked the southern and southwestern inshore coastal waters (Kerr 1985). Bastard trumpeter made up 9.3% (by numbers) of the total scale fish catch for that year (Tasmania, Sea Fisheries Board 1940). Hence, while inshore gill netting was an important fishing method at the time, it was limited, nevertheless, in terms of the numbers and sizes of the fishing vessels participating and, consequently, the ability of these boats to work the more remote inshore waters.

Fishing activity in Tasmania decreased after 1939, due to the outbreak of war (Tasmania, Parliament 1943/44). In the post-war period the fishing fleet increased manyfold, due to the development of fishing for snoek (*Thyrsites atun* Euphrasen) and shark (*Mustelus antarcticus* Gunther and *Galeorhinus australis* Macleay). Inshore gill netting, however, declined markedly as consumer preference turned to imported frozen fish products (Tasmania, Parliament 1982), and bastard trumpeter comprised less than 0.1% (by weight) of the total reported scale-fish catch for 1948 (Tasmania, Parliament 1949).

The reported annual commercial catch of bastard trumpeter declined after 1952, and by 1976/77 it had dwindled to a mere one tonne. Despite this, a significant portion of the Tasmanian fishing fleet continued to engage in inshore gill netting at the end of the period. Of the 139 fishing boats under 6 m in length registered in 1979/80 (excluding 96 abalone boats), 116 were recorded as using gill nets (Tasmania, Parliament 1982). Furthermore, crayfish boats also participated in the scale fishery and accounted for a sizeable portion of the total landed catch of scale fish (Smith & Fergusson 1969). The number of commercial fishing boats engaged in inshore gill netting in 1979/80 was therefore comparable to the number operating in the inshore scale fishery in 1939, and likely to be greater than the number in 1948. The modern boats would also have been larger and more capable of fishing the more distant grounds. It would appear from this that inshore gill netting effort in 1979/80 is likely to have been higher than it was in 1948. The general decline in the reported annual catch of the bastard trumpeter since the mid 1940's, therefore, cannot be explained simply by a decline in fishing effort.

Nor is it likely that the decline in the reported commercial catch of the bastard trumpeter since the 1950's can be attributed simply to a lack of reporting of catches of this fish by commercial

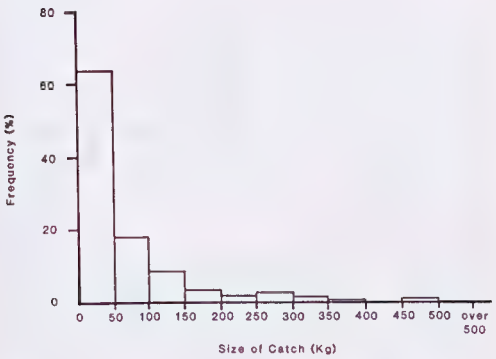

FIG. 3 — Sizes of commercial catches of bastard trumpeter, July 1978 to June 1982.

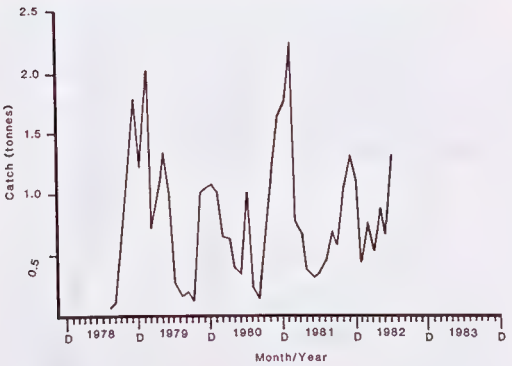

FIG. 4 — Monthly commercial catch of bastard trumpeter, July 1978 to June 1982.

fishermen. While fishing returns are notoriously inaccurate, methods of collection of this data have improved over time and reported catches are likely to have increasingly rather than decreasingly reflected the true catch. The extent of inaccuracies characteristically contained in fishing returns may be gleaned by comparing annual catch data obtained from these fishing returns with similar data obtained by the ABS from fish sales. A manual compilation from fishing returns of the annual trumpeter catch for the four-year period 1978/79 to 1981/82 was used to make such a comparison and the results indicated that the average annual discrepancy between the two sets of data over this period was 2.6 tonnes, with the greatest discrepancy of 6 tonnes occurring in 1978/79. While it is acknowledged, therefore, that fishing returns are inaccurate, the decline in the reported annual commercial catch of trumpeter since 1952 appears sufficiently marked to have been due to causes other than misreporting of catches alone.

THE PRESENT COMMERCIAL CATCH OF BASTARD TRUMPETER

In order to obtain information on the catch-effort and the distribution of the present commercial catch of the bastard trumpeter in Tasmanian waters, computer printout records compiled from monthly fishing returns kept by the Sea Fisheries Department for the period July 1978 to June 1982 were analysed.

Monthly Catch per Boat

The average size of the monthly catch per boat of bastard trumpeter is small. Figure 3 shows the frequency of the monthly catch-size per boat over the period. Less than 10% of the monthly boat catches were over 150 kg, and more than 60% were under 50 kg.

Seasonality of Catch

The monthly catch of bastard trumpeter is highly seasonal, with a tendency to peak in summer and fall over winter (fig. 4). Two reasons may account for this. Firstly, poor weather leads to a general curtailment of fishing in winter. Secondly, commercial crayfishing is totally closed during the months of September and October, and, as commercial gill netting is frequently carried out in conjunction with crayfishing, gill netting activity may also decline during these months, although some crayfishermen supplement their income during the off-season by turning to other fisheries including the scale fishery (Smith & Ferguson 1969).

Distribution of the Commercial Bastard Trumpeter Catch

For the purposes of fisheries statistics, Tasmanian waters are divided into fishing "blocks" defined by one degree of latitude and one degree of longitude (major bays, estuaries and channels are ascribed separate block numbers).

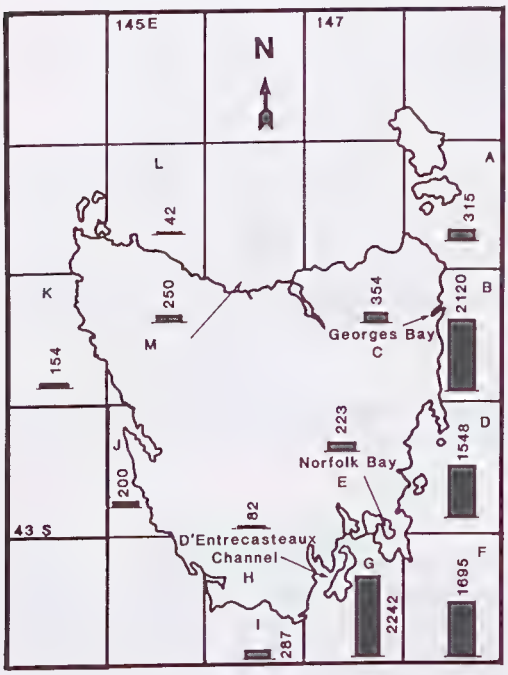

FIG. 5 — Average annual commercial catch (kg) of bastard trumpeter in each fishing block, July 1978 to June 1982.

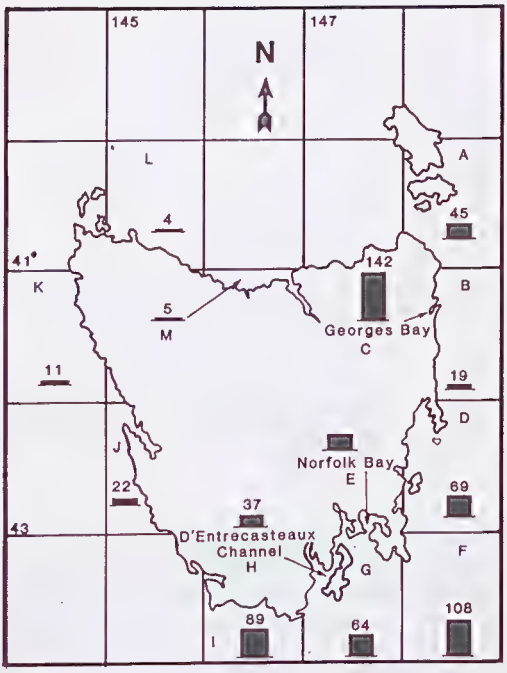

FIG. 6 — Mean catch per boat of bastard trumpeter in each fishing block, July 1978 to June 1982.

The greatest part of the bastard trumpeter catch in Tasmania is made in the waters of the eastern and southeastern coast (fig. 5). Catches made along the southern and western coasts are relatively small, possibly due to lower gill netting effort in these waters, resulting from adverse weather conditions. The sea bed adjacent to the more sheltered northern coast is mostly sandy, and catches there are also low.

Catch-Per-Unit-Effort

Commercial gill netting in Tasmania is a secondary fishing method and fishing returns do not distinguish between the effort associated with gill net catch and that associated with the primary catch. With no other information available, the mean monthly catch per boat is used here as a crude measure of catch-per-unit-effort.

The mean monthly catch per boat was calculated for each block over the four-year period (fig. 6). The eastern and southeastern blocks displayed the highest mean monthly catch per boat, the greatest value being 142 kg in Georges Bay (block C). The northern and western blocks showed a low mean monthly catch per boat, but that of the southern block (I) compared favourably with the mean monthly catch per boat of the southeastern blocks (E, F, G & H) and was higher than the two eastern blocks (B & D). While the average catch from block I was low (287 kg), the sizes of the individual catches recorded in this block were high (up to 89 kg).

NON-COMMERCIAL CATCH OF BASTARD TRUMPETER

Amateur Gill Netting

As amateur net fishing in Tasmania does not require a licence, no direct information exists relating to the extent of amateur gill netting or the size of the annual bastard trumpeter catch taken by this sector. There is, however, indirect information

which suggests that amateur gill netting in Tasmania has increased quite significantly over the past three decades. A study of trends in recreational net fishing in Western Australia between 1950 and 1977 found that the number of persons engaging in this sport increased steadily and significantly over the period, and that the pattern of increased recreational gill netting correlated highly with the increases in average household income (Lenanton 1979).

That present levels of amateur gill netting in Tasmania are high is supported by the results of a 1983 survey of recreational fishing in Tasmania, which found that 6.6% of households (excluding those occupied by commercial fishermen) owned graballs and that an estimated 14 824 persons in Tasmania aged 15 years or more used a graball at least once a year (Australia, ABS 1984). Fifteen per cent of amateurs who owned graballs were found to use them at least once a fortnight. This information, together with the fact that Tasmanian household weekly incomes have risen in a similar manner to those of Western Australia, suggests that amateur gill netting in Tasmania may have increased significantly over the past three decades and that present amateur gill netting effort is of a similar magnitude to that of the commercial sector.

Gill Netting for Crayfish Bait

The range of materials employed by crayfishermen as "crayfish bait" is notoriously wide, and Baker (1982) has claimed that it frequently includes many gill-netted species. The extent to which the more saleable fish captured in gill nets are used for this purpose is not known and is difficult to estimate. It has also been claimed that, since the outlets for small quantities of table fish increased after the mid 1970's, crayfishermen would be more likely to retain the more saleable fish, such as the bastard trumpeter, for sale rather than to use these for craypot bait (Baker 1982).

Smith & Fergusson (1969) reported that commercial crayfishermen rely for the greater part of their bait on frozen fish pieces, and turn to other sources only if the quantity of frozen bait proves inadequate for the fishing trip or if the boat is not equipped with a refrigeration system. These authors suggest that crayfishermen avoid gill netting for bait where possible, as it reduces the time spent crayfishing. However, crayfishermen frequently set one or two nets before dark to collect bait and retrieve these early next morning, that is, the gill netting occurs between pot set and pot collect phases and does not reduce crayfishing time. The large size of the crayfishery in comparison to the inshore gill net fishery means that if even a small percentage of crayfish bait is obtained from netted scale fish, the total amount of scale fish used in this way could be large in comparison to the scale fish catch landed for sale.

DISCUSSION

Regulatory control of inshore gill netting in Tasmania is the most rudimentary of all the Australian States; regulations established late in the nineteenth century have been retained with few changes. Initially a consequence of the island's relatively small population, which buffered for a time the impact of inshore netting, lenient regulation has remained due to resistance to change in the form of a well-entrenched ethos which holds the fish in the sea to be common property and the use of nets to be a natural right of the common person. Lack of research into the effects of this fishing method has permitted this pervasive view to dictate the terms for management of the State's inshore fishery. The appropriateness of lenient regulation has been challenged in all other States, and it is only in Tasmania, Western Australia and South Australia that gill netting by amateurs is not totally prohibited. However, recent biological studies and assessments of fishing levels have led to significant changes in the regulations of both Western and South Australia and it is now only in Tasmania that the question of the appropriateness of present inshore scale fishery management and netting regulation has not been fully addressed.

Tasmanian catch records of the bastard trumpeter *Latridopsis forsteri* can be used to shed light on the long-term consequences of poorly regulated inshore netting. Reports of declining catches prior to 1882 and records of a decline in the commercial catch of bastard trumpeter between 1910 and 1918 strongly suggest an early depletion of populations of this fish in localised inshore bays and estuaries close to major population centres. High commercial catches of the bastard trumpeter during the 1930's were sustained by the exploitation of virgin inshore fishing grounds further afield. A more general and long-term decline in the reported commercial catch has taken place from the early 1950's to the present.

Recreational gill netting activity appears to have increased significantly since the 1950's; survey results indicate that at present the amateur level is comparable with the commercial. Gill netting has

also been a traditional source of bait for crayfishermen and, although the extent to which crayfishermen use netted fish for "craypot bait" may be declining, the quantity of gill-netted fish captured for this purpose is likely to be high in comparison with the quantity landed for sale.

Total gill netting effort in Tasmanian waters has thus increased significantly since the 1950's and this increase could partially explain the general decline in the commercial catch of bastard trumpeter, as commercial and non-commercial gill netting compete for a limited resource. However, the overall increase does not appear to have been sufficient to explain the *magnitude* of the decline in the commercial catch of bastard trumpeter. The lowest recorded commercial catch of one tonne in 1976/77 represented a decrease to one-fiftieth of the peak catch in 1952 and to one-thirtieth of the catch of 1960/61.

While evidence for the long-term decline in the commercial catch of the bastard trumpeter is founded purely on the premise that fishing returns reflect the true catch, and uncertainty with regard to the reliability of commercial fishing returns clouds the issue and places limits on the conclusions which may be drawn, it must be recognised that no other data currently exist by which to gauge the state of this fishery. Furthermore, the findings of the present study are corroborated by the circumstantial evidence reported by Schaap & Green (1988) of a decreasing relative abundance, total abundance and average size in populations of some reef fish species as gill netting pressure is increased. More importantly, the magnitude of the long-term decline in the commercial catch may be explained by the findings of Harries & Lake (1985), who examined the inshore populations of bastard trumpeter and found them to be comprised entirely of juvenile stock. The original intention of authorities, in Tasmania and elsewhere, in setting minimum lengths at which fish could be taken was to ensure that fish spawned at least once before they were captured (Roughley 1951, Gulland 1974). In more recent times, the purpose of the minimum-length regulation has also been to allow fish to attain maximum yield before being harvested. The present minimum legal length at which bastard trumpeter may be taken, set at 12 in. (305 mm) in 1890 and increased only marginally since then to 330 mm (12.9 in.), achieves neither of these objectives.

The potential dangers of concentrating a fishery solely on juvenile stock are well known (Ingpen 1969, Gulland 1974, Allen 1975, Cushing 1977, Francis 1979, 1983). A number of fisheries operating in this manner have exhibited declining catches over a long period, and the collapse of the Atlantic herring fishery, attributed to overfishing of the juvenile stocks, is one of the world's classic fishing industry failures (Cushing 1977). It appears that the inshore gill netting of the bastard trumpeter has focussed entirely on the immature stock, and it is highly likely that much of the observed decline in the commercial catch of this fish can be attributed to this fact.

A review of the regulations pertaining to the Tasmanian inshore scale fishery is long overdue. Tasmania lags behind all other States in this regard and should act as soon as is practicable to protect the viability of its inshore fish species. Biological studies and analysis of catch returns have questioned the appropriateness of current regulation as regards the bastard trumpeter, but many other fish are also taken in nets, including labrids (*Pseudolabrus tetricus* Richardson, *P. psittaculus* Richardson, *P. fucicola* Richardson), leatherjackets (*Penicipelta vittiger* Castelnau, *Meuschenia freycineti* Quoy & Gaimard, *M. hippocrepis* Quoy & Gaimard), morwong (*Nemadactylus macropterus* Bloch & Schneider, *Cheilodactylus spectabilis* Hutton), southern rock cod (*Pseudophycis barbata* Gunther), striped trumpeter (*Latris lineata* Bloch & Schneider), warehou (*Seriolella brama* Gunther), and Australian salmon (*Arripis trutta* Bloch & Schneider). The effects of gill netting on these fish are largely unknown and must also be considered in any proposals for sound management of the inshore gill net fishery.

REFERENCES

Allen, K.R., 1975: The conservation of marine animals. *Search* 6(8): 317–322.

Allport, M., 1870: Proceedings of the Society for May. *Pap. Proc. R. Soc. Tasm.* (1870–1872): 8–10.

Australia, Australian Bureau of Statistics, Tasmanian Office, 1984: *Household Fish Consumption and Non-Commercial Fishing Activities, Tasmania, October 1983.* ABS, Hobart.

Baker, W., 1982: A fisherman's viewpoint. In *Tasmanian Scale Fish Seminar, April 1982.* Tasmanian Fisheries Development Authority, Hobart.

Crowther, W.L., 1920: Notes on Tasmanian whaling. *Pap. Proc. R. Soc. Tasm.* (1919): 130–151.

Cushing, D.H., 1977: *FISH POPULATION DYNAMICS.* John Wiley & Sons, Brisbane.

Dix, T.G., 1974: Derwent estuary net fishing survey. *Tas. Fish. Res.* 8(1): 11–21, 22–24.

Edgar, G.T., Last, P.R. & Wells, M.W., 1982: *COASTAL FISHERIES OF TASMANIA AND BASS STRAIT.* Cat and Fiddle Press, Hobart.

FRANCIS, M.P., 1979: A biological basis for the management of moki, *Latridopsis ciliaris*, and smoothhound, *Mustelus lenculatus*, fisheries. Unpubl. M.Sc. thesis, Canterbury Univ., Christchurch.

FRANCIS, M.P., 1983: Rig overfished in South Island. *Catch* 10(8): 13–14.

GULLAND, J.A., 1974: *THE MANAGEMENT OF MARINE FISHERIES*. Scientechnica Ltd, Dorchester.

HARRIES, D.N. & LAKE, P.S., 1985: Aspects of the biology of inshore populations of bastard trumpeter, *Latridopsis forsteri* (Castelnau, 1872) in Tasmanian waters. *Tas. Fish. Res.* 27 (October): 19–43.

HARRISON, A.J., 1982: The management of scale fisheries. In *Tasmanian Scale Fish Seminar, April 1982*. Tasmanian Fisheries Development Authority, Hobart.

INGPEN, R., 1969: Man in the environment. *Australian Fisheries* 28(6): 7–15.

JOHNSTON, R.M., 1882: General and critical observations on the fishes of Tasmania with a classified catalogue of all known species. *Pap. Proc. R. Soc. Tasm.*: 53–144.

JOHNSTON, R.M., 1890: Further observations upon the fishes and fisheries of Tasmania, together with a revised list of the indigenous species. *Pap. Proc. R. Soc. Tasm.*: 22–46.

JONES, G.H., 1979: *BIOLOGICAL INVESTIGATIONS ON THE MARINE SCALE FISHERY IN SOUTH AUSTRALIA*. 2nd edition. Department of Agriculture and Fisheries, South Australia.

JONES, G.H., 1981: The recreational fishery in metropolitan coastal waters. *SAFIC* 5(6): 9–11.

JONES, G.K., 1986: *A REVIEW OF THE RECREATIONAL AND COMMERCIAL MARINE SCALE FISH RESOURCE IN PORT LINCOLN WATERS: A DISCUSSION PAPER*. South Australian Department of Fisheries, Adelaide.

KERR, G., 1985: *CRAFT AND CRAFTSMEN OF AUSTRALIAN FISHING, 1870–1970: AN ILLUSTRATED ORAL HISTORY*. Mains'l Press, Preston.

LENANTON, R.C.J., 1979: The inshore marine and estuarine licensed amateur fishery of Western Australia. *Fish. Res. Bull. West. Aust.* 23(1): 1–33.

LENANTON, R.C.J., 1984: *THE COMMERCIAL FISHERIES OF TEMPERATE WESTERN AUSTRALIA: EARLY SETTLEMENT TO 1975. Dep. Fish. Wildl. Rep.* No. 62. W.A. Department of Fisheries and Wildlife, Perth.

MACDONALD, N., 1984: Some interesting changes in South Australia's fisheries. *SAFIC* 10(1): 4–6.

MURRAY, L.C., 1927: An account of the whaling and sealing industries of Van Diemen's Land to 1850. Unpubl. B.A. Hons thesis, Univ. Tasm., Hobart.

NICOL, D.J., 1986: *HUMAN INTEREST IN THE TASMANIAN CETACEAN FAUNA. Cent. Environ. Stud. Res. Rep.* No. 26. University of Tasmania, Hobart.

O'KELLY, B.M., 1976: *RECOMMENDATIONS FOR THE COMMERCIAL DEVELOPMENT OF THE TASMANIAN SEA FISHING INDUSTRY*. Dep. Agriculture, Hobart.

PERRIN, R.A. & HAY, P.R., 1987: A history of the Tasmanian scallop industry: diagnosing problems of management. *Pap. Proc. R. Soc. Tasm.* 121: 1–14.

POWNALL, P., 1979: *FISHERIES OF AUSTRALIA*. Farnham, Sydney.

ROUGHLEY, T.C., 1951: *FISH AND FISHERIES OF AUSTRALIA*. Angus and Robertson.

SCHAAP, A. & GREEN, R., 1988: The communities on reefs subjected to different levels of fishing pressure. *Tech. Rep. No.* 31. Department of Sea Fisheries, Hobart.

SMITH, J.T. & FERGUSON, D.J., 1969: The Tasmanian crayfishery — an economic survey 1964/65. *Tas. Fish. Res.* 2: 1–28, suppl.

STEAD, D.G., 1910: *A BRIEF REVIEW OF THE FISHERIES OF NEW SOUTH WALES: PRESENT AND POTENTIAL*. N.S.W. Government Publisher, Sydney.

SUMNER, C.E., 1972: Oysters and Tasmania. *Tas. Fish. Res.* 6(2): 1–15.

TASMANIA, ATTORNEY GENERAL'S DEPARTMENT, 1928: Correspondence of L. Rodway, Chairman of the Royal Society of Tasmania, to the Attorney General dated 22 June, 1926. Files of the Attorney General's Dep., Archives of Tasmania, File No. AGD.1.70 in 69/4956.

TASMANIA, ATTORNEY GENERAL'S DEPARTMENT, 1940: Report on Inquiry: Danish seining in Derwent Estuary waters (Report of Inquity and evidence given). File of the Attorney General's Dep., Archives of Tasmania, File No. AGD.1.192 in 113/4/40.

TASMANIA, PARLIAMENT, 1860: Salmon: Report of Mr Black on the introduction of salmon. *House of Assembly Journals*, vol.V, no.38.

TASMANIA, PARLIAMENT, 1882: Royal Commission on the Fisheries of Tasmania: Report of the Commissioners. *House of Assembly Journals*, vol.XLIII, no.132.

TASMANIA, PARLIAMENT, 1884: Fisheries of Tasmania: Report by W. Saville Kent, F.L.S., F.Z.S. *J. Pap. Parl.*, vol.III, no.78.

TASMANIA, PARLIAMENT, 1885: Fisheries Department: Report of the year terminating 31 July, 1885. *J. Pap. Parl.*, vol.VI, no.90.

TASMANIA, PARLIAMENT, 1886: Correspondence between the Salmon Commissioners and Chief Secretary as to the relations between the Salmon Commissioners and Mr Saville Kent. *J. Printed Pap. Parl.*, vol.IX, no.153.

TASMANIA, PARLIAMENT, 1887: Fisheries Department: Report for the year terminating 31 May, 1887. *J. Pap. Parl.*, vol.XI, no.31.

TASMANIA, PARLIAMENT, 1888/1889a: Report by Sir Thomas Brady, and remarks thereon by Mr W. Saville-Kent, Inspector of Fisheries. *J. Pap. Parl.*, vol.XV, no.105A.

TASMANIA, PARLIAMENT, 1888/1889b: Fisheries Department: Report for the year ending 31 May, 1888. *J. Pap. Parl.*, vol.XV, no.65.

TASMANIA, PARLIAMENT, 1888/1889c: Fisheries Board Report: Nov. 1887 to June 1888. *J. Pap. Parl.*, vol.XV, no.105.

TASMANIA, PARLIAMENT, 1889: Concise history of the acclimatisation of the Salmonidae in Tasmania by

P.S. Seager, Secretary to the Fisheries Board of Tasmania. *J. Pap. Parl.*, vol.XVIII, no.109.

TASMANIA, PARLIAMENT, 1913: Deep-sea fisheries: Report of the Select Committee. *J. Pap. Parl.*, vol.LXIX, no.48.

TASMANIA, PARLIAMENT, 1916/1917: Royal Commission on Tasmanian Fisheries: Report of the Commissioner. *J. Pap. Parl.*, vol.LXXV, no.10.

TASMANIA, PARLIAMENT, 1917: Commissioners of Fisheries: Report for 1916–17. *J. Pap. Parl.*, vol.LXXVII, no.52.

TASMANIA, PARLIAMENT, 1919/1920: Commissioners of Fisheries: Report for the year 1918–19. *J. Pap. Parl.*, vol.LXXXI, no.54.

TASMANIA, PARLIAMENT, 1920/1921: Commissioners of Fisheries: Report for the year 1919–1920. *J. Pap. Parl.*, vol.LXXXIV, no.63.

TASMANIA, PARLIAMENT, 1943/1944: Department of Agriculture: Annual report for 1943–44. *J. Pap. Parl.*, vol.CXXXI, no.15.

TASMANIA, PARLIAMENT, 1949: Department of Agriculture: Annual report for 1948–49. *J. Pap. Parl.*, vol.CXLI, no.40.

TASMANIA, PARLIAMENT, 1982: Review of the Tasmanian fisheries and the operations of the Fisheries Development Authority. *J. Printed Pap. Parl.*, vol.207, no.35.

TASMANIA, PARLIAMENT, 1984: Report of the review of the Fisheries Development Authority, July 1984. *Printed Pap. Parl.*, vol.211, no.41.

TASMANIA, SEA FISHERIES ADVISORY BOARD, 1941: Minutes of the S.F.A.B. meetings 1941. Archives of Tasmania file H 191/6.

TASMANIAN, SEA FISHERIES ADVISORY BOARD, 1947: Minutes of th S.F.A.B. meetings 1947. Archives of Tasmania file H 177/6.

TASMANIA, SEA FISHERIES ADVISORY BOARD, 1958: The Hobb's Report, Minutes of the S.F.A.B. meetings 1958. Archives of Tasmania file H 190/4.

TASMANIA, SEA FISHERIES BOARD, 1930: Report of the Board for the years 1926–1929. Sea Fisheries Board, Hobart.

TASMANIA, SEA FISHERIES BOARD, 1933: Report of the Board for the years 1930–1932. Sea Fisheries Board, Hobart.

TASMANIA, SEA FISHERIES BOARD, 1940: Report of the Board for the years 1933–1939. Sea Fisheries Board, Hobart.

VIVIAN, H., 1983: Natural history and status of the Australian fur seal, *Arctocephalus pusillus doriferus*. In *Tasmanian Waters, Environmental Studies Project Rep. No.1, 1982/1981*. Board of Environmental Studies, University of Tasmania, Hobart.

WINSTANLEY, R.H., 1973: Rock lobster fishing in Tasmania, 1904–1972. *Tas. Fish. Res.* 7: 1–23.

WINSTANLEY, R.H., 1985: Marine fisheries management in Victoria — balancing commercial and amateur fishing interests and community expectations against limited resources. *Mar. Fisheries Rep. No.*4. Commercial Fisheries Branch, Department of Agriculture and Rural Affairs, Melbourne.

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EARLY DEVONIAN GRAPTOLITES FROM TASMANIA

by M. R. Banks and R. B. Rickards

(with one table, three text-figures and one plate)

BANKS, M. R. and RICKARDS, R.B.,1989 (31:x): Early Devonian graptolites from Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 111–117. ISSN 0080–4703. Department of Geology, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001 (MRB); Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK (RBR).

Monograptus thomasi Jaeger occurs in siltstone just east of Flowery Gully in northern Tasmania and indicates an early Devonian age for the host rocks.
Key Words: Devonian, graptolites, Tasmania, *Monograptus*.

INTRODUCTION

Monograptus aequabilis cf. *notoaequabilis* Jaeger & Stein, 1969 has recently been reported from the Mathinna Beds near Scamander in northeastern Tasmania (Rickards & Banks 1979). Late in February 1983, a group of students (S. Capp, J. Lea, A. Tidswell and N. Wright) found *Monograptus* in medium to dark-grey slaty siltstones on Bulls Road, east of Flowery Gully (146°50'E, 41°16'S). They found graptolites at two localities near the same road junction (universal grid reference Zone 55G DQ 8569.3165; Tasmanian 1:100 000 map series Tamar 8215), one 44 m down the road to the southwest and the other 92 m up the road to the south (fig. 1). Subsequently graptolites were also found 28 m and 54 m up the road to the south. It is clear that graptolites occur on at least three horizons, as the siltstone has a fairly constant dip to the north-northeast. The 92 m locality on the upper road and the 44 m locality on the lower road are probably on the same horizon. The graptolitic horizons occur within about 30 m stratigraphically of one another. On the same bedding surfaces as the graptolites and also stratigraphically below are poorly-preserved plant remains, both stems and elliptical bodies (probably sporangia).

STRATIGRAPHY AND AGE

The lowest graptolitic bed lies, at most, 85 m stratigraphically below a bed with bivalves (e.g. *Praecardium* sp.), orthoconic cephalopods, rare trilobites (phacopids) and extremely abundant dacryoconarids. The presence of *M. thomasi* Jaeger shows this particular part of the sequence to be early Devonian in age. In the Melborne Trough in Victoria, *M. thomasi* is restricted to the Wilson Creek Shale and its equivalents (e.g. Killingworth Formation), and is the nominal species for the *M. thomasi* Assemblage Zone of Pragian age (Garratt 1983). The level of the *M. thomasi* Zone in the Pragian was discussed in the same paper but there are apparently some biostratigraphical anomalies yet to be resolved; provisionally Garratt (1983: 81) regarded the *M. thomasi* Zone as early Pragian.

IMPLICATIONS

The association of *M. thomasi* with plants occurs both at Flowery Gully and in the Melbourne Trough in Victoria, but the Tasmanian plant material cannot yet be identified. In the Melbourne Trough, *M. thomasi* occurs below *M. aequabilis notoaequabilis* for the most part, but the species overlap in the top part of the Wilson Creek Shale (Garratt 1983).

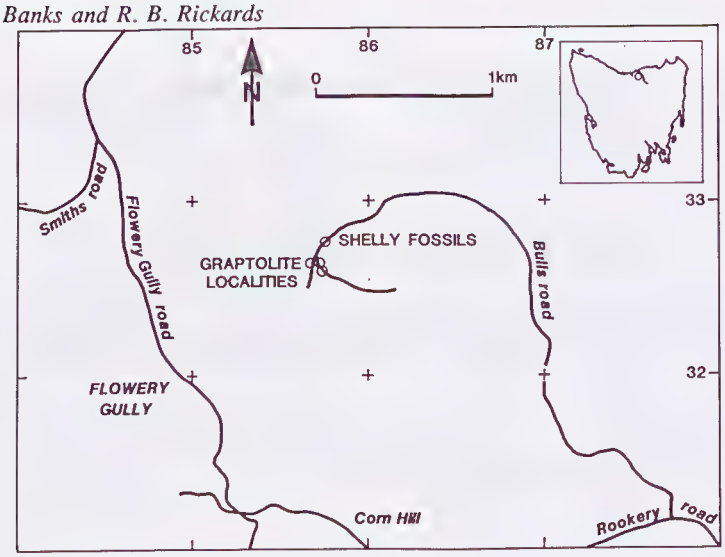

FIG. 1 — Locality map.

Rickards & Banks (1979) have reported *M. aequabilis* cf. *notoaequabilis* from the Mathinna Beds near Scamander in northeastern Tasmania. The graptolitic beds east of Flowery Gully are thus of the same age as or slightly older than the graptolitic beds in the Mathinna Beds at Scamander.

SYSTEMATIC PALAEONTOLOGY

Genus *Monograptus* Geinitz 1852
Monograptus thomasi Jaeger 1966
Figs 2, 3; pl. 1

1906 *Monograptus dubius* Suess; T.S. Hall 1906, 267, fig. 3.
?1906 *M.* cf. *dubius* Suess; T.S. Hall 1906, 268.
?1906 *M.* sp. T.S. Hall 1906, 268.
?1907 *M.* cf. *dubius* Suess; T.S. Hall 1907, 140–141.
?1907 *M.* cf. *crenulatus* (Tornquist); T.S.Hall 1907, 140–141.
?1907 *M.* sp. (*colonus* group); T.S.Hall 1907, 140–141.
?1925 *M. dubius et al.;* Baragwanath, 21–22.
1933 *Monograptus riccartonensis* Lapworth; Keble, 293, pl.
1935 *Monograptus uncinatus* var. *orbatus* Wood; Elles, *in* Lang & Cookson, 422, pl. 32, figs 51–53.
1935 *Monograptus uncinatus* var. *microspora* (sic)(Jaekel); Elles, *in* Lang & Cookson, 422.
1935 *Monograptus chimaera* (Barrande); Elles, *in* Lang & Cookson, 422.
1935 *Monograptus galaensis* Lapworth; ex *Monograptus* cf. *galaensis* Lapworth, Thomas identification, *in* Lang & Cookson, 422.
1937 *Monograptus uncinatus* var. *orbatus* Wood; Harris & Thomas, 69–73, pl. 2, figs 23–25, ?26, 27–28, non 29.
?1937 *M. uncinatus* var. *micropoma* (Jaekel); Harris & Thomas, 69, 73–74, pl. 2, fig. 30.
1960 *M. uncinatus* var. *orbatus* Wood; Thomas, fig. 187.
1964 *Monograptus* sp. nov. (of the *M. hercynicus* type) forma A and B; Berry, 9–13, fig. 1a, b, pls 1–2.
1966 *Monograptus thomasi* n.sp.; Jaeger 1966, 403-411, pl. 41, figs 3-5; pl. 42, figs 2–7; pl. 43, figs 1a–c, o.
1970 *Monograptus thomasi* Jaeger; Jaeger 1970, 175–180.
1971a *Monograptus thomasi* Jaeger; Lenz & Jackson, 13–14, pl. 2, figs 1–4, text-figs 3A, B, H, I.
?1971b *Monograptus* cf. *thomasi;* Lenz and Jackson, 131.
1973 *Monograptus thomasi* Jaeger; Jaeger 1973, 107, fig. 1n.
1975 *Monograptus thomasi* Jaeger; Mu & Ni Yu-nan, 22–24; pl.7, figs 1–4, 8–11; pl. 8, figs 8b, 30.
1977 *M. thomasi* ; Wang Xiao-feng 1977, 196, table 1.
1978 *Monograptus thomasi* Jaeger; Jackson, Lenz and Pedder, pl. 4, fig. 5.

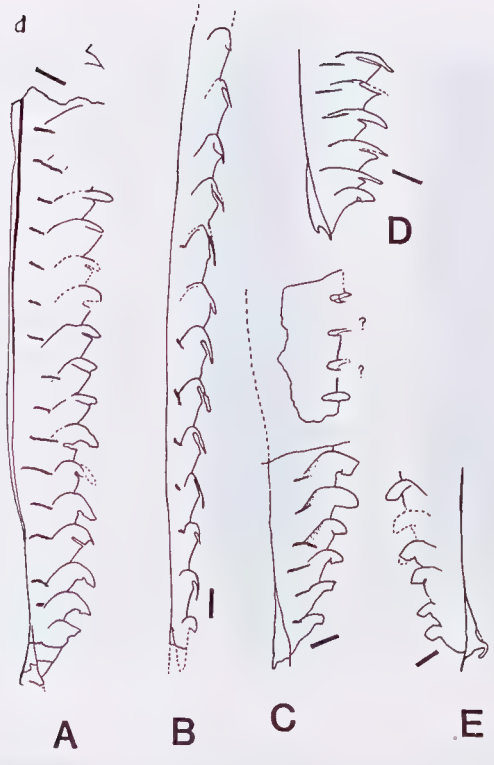

FIG. 2 — Monograptus thomasi *Jaeger, Bulls Road, east of Flowery Gully, Tasmania; all x5; black bars indicate tectonic stretching direction: (A) stipe showing dorsal curvature, nema, sicula and hooded thecae, UTGD 121987(b, vi); (B) stipe showing tendency for thecae to develop proximo-ventrally directed spines, UTGD 121997; (C) sicular end of stipe showing sicula, UTGD 121987(b, iv); (D) proximal end of most deformed specimen showing "added on" sicula and proximal, hooded thecae and dorsal tongue, UTGD 121987(a,i); (E) proximal end showing sicula with dorsal tongue, hooded proximal thecae, UTGD 121987(a, viii); (F) proximal end showing dorsal curvature, sicula with dorsal tongue, trace of virgella and hooded proximal thecae, UTGD 122347(a); (G) a stipe oriented at a high angle to "b", the stretching direction; N.B. stipe width, ventrally curved dorsal tongue and virgella, UTGD 123762b; (H) a stipe oriented parallel to "b"; N.B. stipe width, straightness of sicula, dorsal tongue and virgella, UTGD 123762a.*

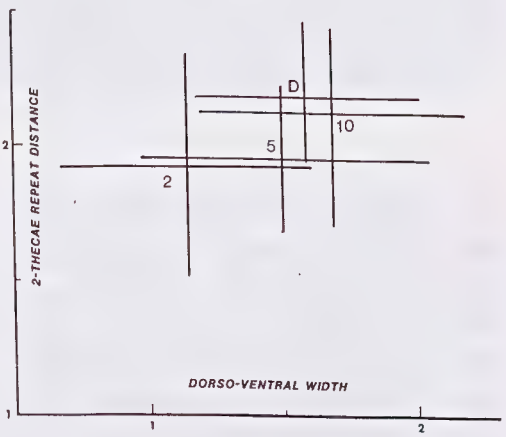

FIG. 3 — Monograptus thomasi *Jaeger, Bulls Road, east of Flowery Gully, northern Tasmania. Graph showing the mean and standard deviation of two thecae repeat distance against ventral width at th2, th5, th10 and distal theca (D); measurements in millimetres.*

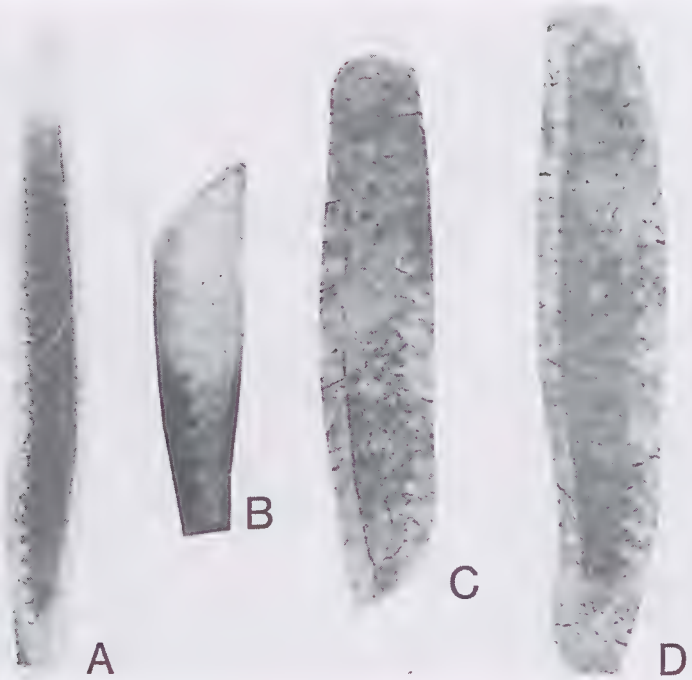

PLATE 1

Monograptus thomasi *Jaeger, Bulls Road, east of Flowery Gully, northern Tasmania: (A) stipe showing curvature and thecal shapes; proximal part unstained, distal part iron-stained, UTGD 123613, × 2.5; (B) stipe showing thecal shape, dorsal curvature and effects of deformation, UTGD 123762a, × 3.75; (C) stipe showing some details of proximal end and thecal shape, UTGD 121987 b(iii), × 4; (D) stipe showing dorsal curvature and some proximal thecae, UTGD 121987 b(iv), × 7.5.*

1979 *Monograptus thomasi* ; Koren', 99–100, fig. 5.4.
1980 *Monograptus thomasi* ; Wang Xiao-feng 1980, chart 2, fig. 2.
1984 *Monograptus thomasi* Jaeger; Porebska, 113, 174, fig. 7.
1984 *Monograptus thomasi* Jaeger; Garratt & Rickards, fig. 8E.
1985 *Monograptus thomasi* Jaeger; Ni Yu-nan, 7; pl.3, fig. 6; pl.4, figs 3,6.
1987 *Monograptus thomasi* Jaeger; Garratt & Rickards, fig. 2i.
1988 *Monograptus thomasi thomasi* Jaeger; Jaeger, 433, fig. Q.

Material and Preservation

Several hundred rhabdosomes were studied, mostly from the 44 m locality, about 40 having preserved proximal ends. Preservation is as micaceous, muddy infills or as external moulds picked out lightly in ferruginous material in medium to dark grey siltstones, some of which are slates. Cleavages are at 30°–60° to the bedding, the latter often being emphasised by paler, coarser silt. There is some preferred orientation of rhabdosomes (e.g. UTGD 121987, 122327, 122337). The specimens are deformed by the development of cleavage and in the description below the measurements given first are the corrected figures (or of specimens lying at 45° to the intersection lineation *B* of cleavage on the bedding, which is the tectonic *b* axis); the figures in brackets, following those for each

dimension, indicate the range of values caused by the deformation. All the material is deposited in the Department of Geology, University of Tasmania, slab nos. UTGD 121987–122001 at 92 m; 122002–122035 at 44 m; 122325–122328 at 28 m; 122329–122340 at 54 m; 122341–122347 at 92 m; 123760–123799 at 92 m.

Diagnosis

Rhabdosomes medium-sized, 30 mm long (20–50), more or less straight except for characteristic gentle double-curvature at proximal end involving thecae 4–11; thecae with hoods decreasing in size distally and more readily exposing the ventral part of the thecal aperture; first few thecae have a slight tendency to metathecal isolation; sicula conspicuously placed dorsally, with pronounced, incurved dorsal tongue; dorso-ventral width at th 1' hood is about 1.0 mm (0.5–1.5 mm); more distally is 1.8–2.1 mm (1.2–2.6 mm); thecal spacing is 10–12 over first few mm (8–15) and 9–10 distally to this (6–13).

Description

The rhabdosome has a very characteristic curvature at the proximal end; the ventral margin of the rhabdosome remains almost straight but the dorsal margin bends sharply towards the ventral side in the region of th 4–th 11. There is, thus, a fairly rapid increase in dorso-ventral width at this point, and the overall aspect of the proximal end is one of gentle double-curvature and attenuation. With specimens at right angles to tectonic *b* this feature is exaggerated, but the proximal end itself may appear relatively robust (figs 2C,D,E). Those specimens lying parallel to tectonic *b* have the characteristic curvature lessened, and the whole rhabdosome is typically slender. Specimens at 45° to the lineation in *b* are of a shape and dimension intermediate between the other two extremes, and they are probably close to the original (but flattened) dimensions of the graptolite.

The sicula is in a conspicuously dorsal position on the rhabdosome. Its apex reaches to between the hoods of th 1 and th 2, except in the most deformed specimens lying at right angles to the lineation (fig. 2D), where the thecae may have succumbed to deformation more than the sicula itself has been deformed. The sicular aperture has a short virgella and a very pronounced and incurved dorsal tongue (figs 2D,E,F,G).

The angle of growth of th 1 away from the sicula (i.e. its free ventral wall) is entirely dependent upon the direction of deformation (cf. figs 2G and 1H) but th 1 is always as large as, or larger than th 2 and th 3. All the thecae are hooded but the hood is less recurved in the distal thecae and the ventral apertural lip is usually visible beneath it: a slit is seen between the hood and the ventral apertural margin. In severely deformed specimens lying parallel to tectonic *b*, the hood may appear as a spine (fig. 2H). The thecal spacing is 10–12 over the first few mm (8–15), the mean being a little over 10; more distally to this region the thecal spacing is fairly constant at 9–10 (6–13). The two thecae repeat distance (TTRD) increases from 1.92 mm ($TTRD^{2}$) to 2.2 mm ($TTRD^{dist}$).

Thecal overlap is always low but increases to about 1/3–1/2 distally from a much smaller value at th 1 and th 2. The base of the interthecal septum is often visible and is slightly thickened. The dorso-ventral stipe width conspicuously reflects the tectonic deformation, especially on slabs with numerous randomly oriented specimens, those specimens at right angles to the lineation being very broad and those parallel to the lineation very narrow. Thus, at the level of the hood of th 1 the dorso-ventral width has a full range of 0.5–1.5 mm, specimens at 45° to the lineation most commonly being about 1.0 mm (0.80–1.30 mm is the full range measured when at 45° to the lineation). The distal dorso-ventral width is 1.8–2.1 mm (1.2–2.6 mm), and the maximum may be reached in a few mm from the proximal end.

Remarks

When due allowances are made for tectonic deformation, the Flowery Gully specimens are remarkably close to the originals described by Jaeger (1966). The only slight differences are that th 1 is a fraction less conspicuous in its ventro-dorsal extent relative to th 2, and the thorn-like proximal aspect is possibly a little less pronounced than in the Victorian material. However, on both counts the Flowery Gully specimens match several of Jaeger's figured specimens (e.g. pl. 42, figs 2, 4 & 5; pl. 43, left-hand specimen and the proximal end near the bottom of the plate). The Flowery Gully specimens are undoubtedly more deformed than those figured by Jaeger, but it is noticeable that the closest agreement (listed above) is with his tectonically deformed specimens (though in the text he does not give dimensions for these). Some of the deformation of the Flowery Gully specimens is

TABLE 1

Statistical Comparison of Tasmanian with Victorian Specimens of *M. thomasi

	Two thecae repeat distance (mm)				
	N	Mean	s	t	P
Theca 2					
Tas.	13	1.92	0.417	0.49	>0.50
Vic.	5	1.82	0.183		
Theca 5					
Tas.	12	1.95	0.269	0.06	>0.50
Vic.	5	1.94	0.361		
Theca 10					
Tas.	9	2.12	0.416	0.09	>0.50
Vic.	4	2.1	0.324		
Distal theca					
Tas.	5	2.18	0.248	0.62	>0.5
Vic.	2	2.05	0.05		

* Victorian specimens from Woods Point area; Tasmanian specimens from Flowery Gully, in the collection of the Department of Geology, University of Tasmania.
s = standard deviation.
t = the "t statistic" of the two samples.
P = probability that the two samples are part of the same population.

of the type referred to by Jaeger (*op. cit.*: 404) where the greatest deformation is in petrofabric direction *a*, resulting in rather higher thecal spacings irrespective of angle to lineation *B*. TTRD measurement of similarly deformed Victorian specimens (table 1) shows a close resemblance between the two forms, although there is a little less correspondence when dorso-ventral width is considered.

The TTRDs for the collections from Tasmania and Victoria were statistically analysed (table 1). The two collections showed very strong correlations of TTRD at corresponding thecae and are, undoubtedly, on this basis the same species.

The final point to note in relation to the Victorian originals is that, whilst the thecal overlap of the Flowery Gully material compares well with the photographs of Jaeger (1966: pls 42, 43), they compare less well with his line drawings (figs 1a–c).

The characters of the proximal end distinguish *M. thomasi* from other species rather easily, only those severely deformed at right angles to lineation *B* superficially resembling *M. praehercynicus* Jaeger and *M. subhercynicus* Willifert. Jaeger (*op. cit.*: 407–410, fig. 1) has given detailed comparisons with earlier described species, with which the authors concur. *M. pacificus* and *M. craigensis* differ from *M. thomasi* on thecal count, stipe width and proximal curvature. *M. sudeticus* Porebska has distinct ventral curvature proximally. *M. telleri* Lenz and Jackson is clearly quite close to *M. thomasi*, *M. telleri telleri* is rather narrower but with similar maximum dorso-ventral width and thecal spacing. The main difference between the two is the total lack of metathecal isolation in *M. telleri*. *M. telleri zdanoviensis* Porebska is a more robust sub-species with greater thecal overlap and thecal spacing than *M. thomasi*, but some late specimens recently figured by Porebska (1984: figs 22.21 and 22.22) have similar proximal curvature: Porebska (*op. cit.*) derived both *M. craigensis* and possibly *M. thomasi* from these late forms of *M. t. zdanoviensis*, near the base of the *craigensis* Zone. We would concur with this suggested derivation of *M. thomasi*, for it fits the known stratigraphic occurrences and requires only a slight increase in the proximal curvature of the rhabdosome, coupled with lessening of the thecal spacing and a slight tendency to metathecal isolation.

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Dr P.A. Jell, Museum of Victoria, made specimens of *M. thomasi* from Victoria available from the collections of the Museum. Penny Green assisted in preparation of the manuscript and Mr Fred Koolhof took the photographs. To these people we are grateful.

REFERENCES

BARAGWANATH, W., 1925: The Aberfeldy district, Gippsland. *Mem. Geol. Surv. Vict.* 15: 19–22.

BERRY, W.B.N., 1964: Siluro-Devonian graptolites from Eildon, Victoria. *Aust. J. Sci.* 26: 223–224.

CHURKIN, M., JAEGER, H. & EBERLEIN, G.D., 1970. Lower Devonian graptolites from southeastern Alaska. *Lethaea* 3: 183–202.

ELLES, G.L. *In* LANG, W.H. & COOKSON, I.C., 1985: On a flora including vascular land plants, associated with *Monograptus*, in rocks of Silurian age, from Victoria, Australia. *Phil. Trans. R. Soc. Lond.* 224: 421–449.

GARRATT, M., 1983. Silurian and Devonian biostratigraphy of the Melbourne Trough, Victoria. *Proc. R. Soc. Vict.* 95: 77-98.

GARRATT, M.J. & RICKARDS, R.B., 1984: Graptolite biostratigraphy of early land plants from Victoria, Australia. *Proc. Yorkshire Geol. Soc.* 44(4): 377–384.

GARRATT, M.J. & RICKARDS, R.B., 1987: Pridoli (Silurian) graptolites in association with *Baragwanathia* (Lycophytina). *Bull. Geol. Soc. Denmark* 35: 135–139.

HALL, T.S., 1906: Reports on graptolites. *Rec. Geol. Surv. Vict.* 1: 226–278.

HALL, T.S., 1907: Reports on graptolites. *Rec. Geol. Surv. Vict.* 2: 137–143.

HARRIS, W.J. & THOMAS, D.E., 1937: Victorian graptolites (New Series). Part IV. *Min. & Geol. J. Vict.* 1: 69–79.

HOWE, M.P.A., 1983: Measurement of thecal spacing in graptolites. *Geol. Mag.* 120: 635–638.

JACKSON, D.E., LENZ, A.C. & PEDDER, A.E.H., 1978: Late Silurian and Early Devonian graptolite, brachiopod, and coral faunas from Northwestern and Arctic Canada. *Geol. Assoc. Can. Spec. Pap.* 17: 1–159.

JAEGER, H., 1966: Two late *Monograptus* species from Victoria, Australia, and their significance for dating the *Baragwanathia* flora. *Proc. R. Soc. Vict.* 79: 393–413, pls 41–43.

JAEGER, H., 1970: Remarks on the stratigraphy and morphology of Pragian and probably younger monograptids. *Lethaia* 3: 178-182.

JAEGER, H., 1973: About Lower Devonian Graptoloidea. *Stratigrafiya nizhnego i srednego devona, Mezhdunar. Simp. Granitsa Silura Devona, Biostratigr. Silura, Nizhnego Srednego Devona., Tr. 3*(2): 99–109.

JAEGER, H., 1988: Devonian graptolites. In *DEVONIAN OF THE WORLD. Vol.III. Proc. Second Internat. Symp. on the Devonian System. Calgary, Canada*: 431–438.

KEBLE, R.A., 1933: Middle Silurian land plants. *Vict. Nat.* 49: 293–296, pl.

KOREN', T.N., 1979: Late monograptid faunas and the problem of graptolite extinction. *Acta Pal. Pol.* 24: 79–106.

LENZ, A.C. & JACKSON, D.E., 1971a: Latest Silurian (Pridolian) and early Devonian *Monograptus* of Northwestern Canada. *Bull. Geol. Surv. Can.* 192: 1–25.

LENZ, A.C. & JACKSON, D.E., 1971b: Preliminary investigations of the upper Silurian and lower Devonian graptolite biostratigraphy of the Northwestern Canadian mainland. *Mezhdunar. Simp. Granitsa Silura Devona, Biostratigr. Silura, Nizhego Srednego Devona, Tr.* 3(1): 127–134.

MU, EN-ZHI & NI YU-NAN, 1975: The Silurian and Devonian graptolites from the Qomolangma Feng Region. *Report of Scientific Investigation in the Qomolangma Feng Region. Palaeontology*, Fasc. 1. Sci. Press, Peking: 5–38.

NI YU-NAN, 1985: *In* Mu, En-zhi & Ni Yu-nan: Researches on the graptolites of Xizang (Tibet). *Palaeontologia cathayana* 2: 1–17.

POREBSKA, E., 1984: Latest Silurian and early Devonian graptolites from Zdanow section, Bardo Mts (Sudetes). *Ann. Soc. Geol. Pol.* 52: 89–209.

RICKARDS, R.B. & BANKS, M.R., 1979: An Early Devonian monograptid from the Mathinna Beds, Tasmania. *Alcheringa* 3: 307–311.

THOMAS, D.E., 1960: The zonal distribution of Australian graptolites. *J. Proc. R. Soc. N.S.W.* 94: 1–58.

WANG, X., 1977: The discovery of latest Silurian and early Devonian monograptids from Qinzhou, Guanxi and its (sic) significance. *Acta Geol. Sin.* 2: 190–205.

WANG, X., 1980: On the distribution, zonation and correlation of graptolite-bearing Silurian and early Devonian in China. *Bull. Chin. Acad. Geol. Sci.* 1(2): 23-36.

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MACROLICHENS OF MOUNT WELLINGTON, TASMANIA

by A. V. Ratkowsky, P. W. James, A. W. Archer, G. Kantvilas and D. A. Ratkowsky

(with two tables)

RATKOWSKY, A.V., JAMES, P.W., ARCHER, A.W., KANTVILAS, G. & RATKOWSKY, D.A., 1989 (31:x): Macrolichens of Mount Wellington, Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 119–125. ISSN 0080–4703. 117 York Street, Dynnyrne, Tasmania, Australia 7005 (AVR); Department of Botany, British Museum (Natural History), Cromwell Road, London SW7 5BD, U.K. (PWJ); Division of Analytical Laboratories, Department of Health, PO Box 162, Lidcombe, NSW 2141 (AWA); Tasmanian Herbarium, GPO Box 252C, Hobart, Tasmania 7001 (GK); and CSIRO Tasmanian Regional Laboratories, Stowell Avenue, Battery Point, Tasmania 7004 (DAR), Australia.

A census of the fruticose, foliose and squamulose lichens, also referred to as "macrolichens", was carried out on Mount Wellington, Tasmania, between November 1980 and December 1985. A total of 95 taxa was found, including 32 taxa of *Cladia, Cladina* and *Cladonia*. This contrasts with the findings of a recent survey of macrolichens in Tasmanian rainforests, which reported only eight species from those genera. Mount Wellington had fewer species of *Collema, Menegazzia, Pseudocyphellaria* and *Sphaerophorus*. Thirty-seven species of macrolichens were common to both survey areas. *Ramalea cochleata* is reported from Tasmania for the first time.
Key Words: macrolichens, lichens, Mount Wellington, Tasmania, *Ramalea*.

INTRODUCTION

The lichen flora of Tasmania has not been as thoroughly studied as the flowering plants or bryophytes. Tasmanian lichens were first collected by Labillardière during D'Entrecasteaux's voyage of 1791–94. Other distinguished botanists, such as Robert Brown and Joseph Dalton Hooker, also collected lichens in Tasmania. These collections formed the basis for subsequent studies of this group of plants. The last major revision of the list of Tasmanian lichens was published by the Rev. Francis R. M. Wilson (Wilson 1893). That work contained a list of 151 species, based on his own collections and those of earlier collectors, and included a brief description of each species. Although Leonard Rodway was a significant figure in Tasmanian botany, monographing the phanerogams and bryophytes, he did not study Tasmanian lichens in detail. The history of lichenology in Tasmania, from the early explorers through to the 20th century, has been covered by Kantvilas (1983). An extensive list of lichen collectors in Tasmania prior to 1963 was given by Wetmore (1963), but Kantvilas (1983) noted that the names of Amalie Dietrich and Franz Sieber should have been omitted from that list as neither visited Tasmania.

Mount Wellington, originally known as Table Mountain, rises 1270 m from near the Derwent River, behind Hobart, and has long played an important role in Tasmanian botany. Road accessibility resulted in the mountain being visited by virtually every major plant collector. The wide range of rainfall (from c. 600 mm per annum in the dry sclerophyll foothills to c. 1500 mm per annum in the treeless montane summit region) plus a wide range of geological and soil types (ranging from Permian mudstones and Triassic sandstones in the lower elevations to Jurassic dolerite in the upper regions) provide a multitude of habitat types and broad ecological diversity. This has resulted in Mount Wellington having more than one-third of the known species of Tasmanian flowering plants (Ratkowsky & Ratkowsky 1976) and more than 60% of the known Tasmanian bryophyte flora (Ratkowsky & Ratkowsky 1982). Botanists who have collected lichens on Mount Wellington include R. Brown, J.D. Hooker, R.C. Gunn, W. Archer, T.A. & B. Gulliver, R.A. Bastow, W.A. Weymouth, F.R.M. Wilson, L. Rodway, J.F. Shirley, W.S. Cambell, E. Cheel, A.H.S. Lucas and G.C. Bratt. Thus Mount Wellington has a place of importance in Tasmanian lichenology, as it has in the botany of other plant groups.

THE SURVEY ZONES

Following the pattern of surveys of Mount Wellington in other plant groups (Martin 1940, Ratkowsky & Ratkowsky 1976, 1982), vegetation

zones were defined which were based primarily on the species of eucalypt present. Full details of the vegetation zones were given in Ratkowsky & Ratkowsky (1976) and are summarised briefly in table 1.

SURVEY AND IDENTIFICATION METHODS

The survey zones, visited irregularly between November 1980 and December 1985, were confined mainly to an area similar to that used by Martin (1940). (See Ratkowsky & Ratkowsky 1976, fig. 1, for an approximate boundary of Martin's survey.) The survey area was restricted deliberately because of the difficulty of identifying some lichens in the field. On the bryophyte survey of Ratkowsky & Ratkowsky (1982), no attempt was made to assess the abundance of a species in a given zone, because many species could only be determined with confidence after microscopic examination. Lichen identification is even more problematic, requiring chemical tests and the use of thin-layer chromatography (tlc) for species in many genera.

The results of the present survey (table 2) cannot in any sense be considered to be a complete list of the lichens of Mount Wellington, and must be viewed as a stimulus to others to carry out a more comprehensive study. Attention was directed to the "macrolichens", i.e. species with fruticose, foliose, squamulose or filamentous growth habit. In a few cases, collections were made of crustose species. In view of the difficulty of assessing species abundance, the presence of a macrolichen in a particular zone is indicated (table 2) only by an "X".

TABLE 1

Summary of the Vegetation Zones of Mount Wellington

Zone*	Description	Approximate elevation
1	Treeless upper regions of (i) grassy areas, more or less permanently wet, and (ii) rocky, well-drained areas of shrubs	1220–1270 m
2	Woodlands containing pure stands of *Eucalyptus coccifera*, and treeless marshlands and grasslands at the same elevation	1100–1220 m
3	Woodlands with mixed *E. coccifera* and *E. urnigera* stands, and treeless marshlands and grasslands at the same elevation	800–1100 m
4	Wet sclerophyll forests dominated by *E. delegatensis*	600-800 m
5	Wet sclerophyll forests dominated by *E. obliqua*	below 670 m
6	Sandstone outcrops dominated by *E. johnstonii*, e.g. Snake Plains, The Springs, Sphinx Rock	600–750 m
7	Gully communities, permanently wet, with thick undergrowth of *Bedfordia salicina* and *Olearia argophylla*	below 600 m
8	Dry sclerophyll open forests dominated by *E. pulchella* and *E. viminalis* (on dolerite) or *E. tenuiramis* (on mudstone)	below 500 m

* Zones 3, 4, 5, 6, 7 and 8 correspond respectively to zones 3a, 3b, 4, 5, 6 and 7 of Ratkowsky & Ratkowsky (1976).

TABLE 2

Macrolichens of Mount Wellington

Species	Zone							
	1	2	3	4	5	6	7	8
Baeomyces arcuatus Stirton				x	x			x
B. heteromorphus Nyl. ex Bab. Church. & Mitt.			x	x	x		x	x
Cladia aggregata (Sw.) Nyl.	x	x	x		x	x	x	x
C. fuliginosa R. Filson	x							
C. inflata (F. Wilson) D. Galloway		x						
C. retipora (Labill.) Nyl.	x	x		x		x	x	
C. schizopora (Nyl.) Nyl.				x	x		x	x
C. sullivanii (Müll. Arg.) Martin	x					x		
Cladina confusa (R. Sant.) Follm. & Ahti	x	x		x				
C. mitis (Sandst.) Hustich	x	x						
Cladonia capitellata (J.D. Hooker & Taylor) Church. Bab. var. *capitellata*	x	x	x	x	x	x	x	x
C. capitellata var. *squamatica* Archer						x		
C. cervicornis subsp. *verticillata* (Hoffm.) Ahti	x	x	x	x	x	x	x	x
C. chlorophaea (Flörke) Sprengel		x	x	x	x	x	x	x
C. corniculata Ahti & Kashiwadani	x	x	x	x	x	x	x	
C. cornuta (L.) Hoffm.					x			
C. crispata (Ach.) Flotow		x						
C. cryptochlorophaea Asahina								x
C. fimbriata (L.) Fr.		x			x			
C. furcata (Huds.) Schrader		x						
C. gracilis (L.) Willd. subsp. *tenerrima* Ahti		x						
C. humilis (With.) Laundon var. *humilis*		x	x	x	x	x	x	x
C. krempelhuberi (Vainio) Vainio	x	x	x		x	x		x
C. ochrochlora Flörke				x	x	x	x	
C. pleurota (Flörke) Schaerer	x			x	x	x	x	
C. pyxidata (L.) Hoffm.		x			x			
C. ramulosa (With.) Laundon*	x	x		x	x	x	x	x
C. rigida (J.D. Hooker & Taylor) Hampe	x	x	x	x	x		x	x
C. sarmentosa (J.D. Hooker & Taylor) Dodge				x				
C. scabriuscula (Delise in Duby) Nyl.	x	x	x	x	x		x	
C. subdigitata Nyl.	x	x	x	x			x	
C. sulcata Archer var. *wilsonii* Archer	x	x	x		x			x
C. tessellata Ahti & Kashiwadani		x	x	x	x	x		x
C. weymouthii F. Wilson ex Archer						x		
Collema laeve J.D. Hooker & Taylor							x	
C. subconveniens Nyl.				x				
Flavoparmelia haysomii (Dodge) Hale								x
F. rutidota (J.D. Hooker & Taylor) Hale								x
Hypogymnia billardieri (Mont.) R. Filson								x
H. lugubris (Pers.) Krog	x	x		x	x	x	x	x

cont.

Species	Zone							
	1	2	3	4	5	6	7	8
Hypogymnia mundata (Nyl.) Rassad.				x			x	
H. pulverata (Crombie) Elix							x	
H. turgidula (Bitter) Elix		x	x	x	x		x	
Knightiella splachnirima (J.D. Hooker & Taylor) Gyelnik				x	x	x		
Leptogium victorianum F. Wilson							x	
L. cf. *limbatum* F. Wilson					x	x	x	
Menegazzia platytrema (Müll. Arg.) R. Sant.				x				x
M. subpertusa P. James & D. Galloway								x
Neofuscelia pulla (Ach.) Esslinger					x			x
Neophyllis melacarpa (F. Wilson) F. Wilson					x		x	
Parmelia cunninghamii Crombie							x	
P. salcrambidiocarpa Hale							x	
P. signifera Nyl.	x	x	x				x	
P. tenuirima J.D. Hooker & Taylor						x	x	
Parmelina stevensiana Elix & Johnston								x
Parmotrema chinense (Osbeck) Hale & Ahti								x
P. reticulatum (Taylor) M. Choisy								x
Peltigera dolichorhiza (Nyl.) Nyl.		x	x	x	x		x	x
P. cf. *rufescens* (Weis.) Humb.[†]				x				
Placopsis gelida (L.) Lindsay					x			
Pseudocyphellaria billardierei (Delise) Räsänen							x	
P. crocata (L.) Vainio	x	x		x	x		x	
P. dissimilis (Nyl.) D. Galloway & P. James				x	x		x	
P. glabra (J.D. Hooker & Taylor) Dodge		x	x	x	x		x	
P. neglecta (Müll. Arg.) H. Magn.								x
P. rubella (J.D. Hooker & Taylor) D. Galloway & P. James				x	x		x	
Psoroma asperellum Nyl.							x	
P. hypnorum (Vahl) S. F. Gray		x						
P. microphyllizans (Nyl.) D. Galloway				x			x	
P. pholidotoides (Nyl.) Trevisan					x			
P. soccatum R. Br. ex Crombie[‡]				x				
Ramalea cochleata Müll. Arg.					x			
Ramalina inflata (J.D. Hooker & Taylor)					x			x
R. unilateralis F. Wilson					x			
Siphula complanata (J.D. Hooker & Taylor) R. Sant.	x	x						
S. decumbens Nyl.	x	x						
S. fragilis (J.D. Hooker & Taylor) J. Murray	x	x						

Species	Zone							
	1	2	3	4	5	6	7	8
Sphaerophorus tener Laurer				x			x	
Stereocaulon corticatulum Nyl.			x					x
S. ramulosum (Sw.) Räuschel	x	x	x	x	x		x	x
Sticta stipitata Knight		x						
Thamnolia vermicularis (Sw.) Ach. ex Schaerer var. *vermicularis*	x							
T. vermicularis var. *subuliformis* (Ehrh.) Schaerer	x							
Thysanothecium scutellatum (Fr.) D. Galloway			x		x		x	x
Umbilicaria cylindrica (L.) Delise	x							
Usnea capillacea Motyka		x						
U. inermis Motyka	x	x	x		x	x		
U. scabrida Taylor				x				
U. torulosa (Müll. Arg.) Zahlbr.§		x						
U. sp.¶	x			x	x			
Xanthoparmelia mexicana (Gyelnik) Hale								x
X. neotinctina (Elix) Elix & Johnston								x
X. scabrosa (Taylor) Hale					x			x
X. substrigosa (Hale) Hale					x			x
X. tasmanica (J.D. Hooker & Taylor) Hale								x

* Includes a single specimen containing homosekikaic acid together with fumarprotocetraric acid.
† No substances detected by tlc. Upper surface lightly tomentose towards the tips.
‡ Three additional undetermined taxa were also recorded. One contains porphyrilic acid whilst the others contain only unknown substances.
§ Contains usnic and squamatic acids.
¶ Sorediate species containing usnic acid only.

RESULTS OF THE CENSUS

Ninety-five macrolichens collected in the present survey are listed in table 2, in alphabetical order of the genera. The genera *Cladia, Cladina* and *Cladonia* account for 32 taxa, or more than one-third of the lichens in the survey area. For *Cladina*, the nomenclature of Ahti (1984) has been followed. The two species known from Mount Wellington are both widespread (occurring in both hemispheres) and highly variable. Six Tasmanian species of *Cladia* occur on Mount Wellington. These are the same six that occur in New Zealand (Galloway 1985). *Cladia aggregata* is widespread and abundant on Mount Wellington, and is probably the most common lichen. It is intensely polymorphic.

Twenty-four species of *Cladonia sensu stricto* were found. These ranged from the squamulose *C. sulcata* to *C. chlorophaea*, which often bore 4 cm high podetia that sometimes proliferated at the margins to form several tiers. Species with red apothecia or pycnidia included *C. subdigitata, C. pleurota* and *C. weymouthii*. Other conspicuous species included *C. corniculata*, its subulate podetia with slightly branched apices being an easily recognisable character. *C. capitellata* had a readily identifiable growth form, as its cylindrical podetia, devoid of cups, were erect, crowded and up to 6 cm tall. *C. cervicornis* subsp. *verticillata* and *C. krempelhuberi* had cups with central proliferations. *C. tessellata* was recognised readily with podetia up to c. 1 cm tall, bearing large, rounded brown apothecia at their tips. Difficult to separate *Cladonia* species, containing only fumarprotecetraric acid, included *C. sarmentosa, C. ochrochlora* and *C. ramulosa*.

Species of the foliose genus *Pseudocyphellaria* were conspicuous in the survey area. The two most

frequently collected species were *P. glabra*, which had a pale-green upper surface, white medulla and pseudocyphellae, and finger-like marginal isidia, and *P. crocata*, which had a grey or brown upper surface with yellow soredia, white medulla and yellow pseudocyphellae. A further species, *P. rubella*, was readily recognised when wet by the lettuce-green upper surface, covered with silky white hairs. *P. billardierei* and *P. neglecta* were collected only once.

Another genus widespread in the survey area was *Hypogymnia*, found on most substrates, including bark, twigs, litter, rocks and soil. The two most common species were *H. lugubris* and *H. turgidula*. Only two species of the related genus *Menegazzia*, *M. platytrema* and *M. subpertusa*, were collected.

Other widespread genera in the survey area were members of the family Parmeliaceae, with species of *Flavoparmelia*, *Neofuscelia*, *Parmelia*, *Parmelina*, *Parmotrema* and *Xanthoparmelia* being found. Of the 15 species of Parmeliaceae collected, *Parmelia signifera* was most frequent. Except for that species, all other species of the family were found in zones of low elevation.

The most exciting find of the survey was *Ramalea cochleata*, this being the first record of this genus and species in Tasmania. Of the remaining macrolichens, *Baecomyces arcuatus* and *B. heteromorphus* had conspicuous pinkish apothecia and covered soil banks over a wide area. *Knightiella splachnirima* was another species with pink apothecia, but these scarcely protruded above the green basal squamules. Another species with pinkish or light-brown apothecia was *Thysanothecium scutellatum*, easily recognised by its fissured pseudopodetia, which gave it a "shredded" appearance. Three species of *Siphula* were found above 1100 m. *Stereocaulon ramulosum* was a conspicuous, widespread species, growing in all zones. Its thallus was typically up to 250 mm tall, attached to rocks with a strong holdfast, and had numerous cephalodia which gave it a bluish-grey colour. The genus *Usnea* was represented predominantly by *U. inermis*, which grows on dead trees. The genus *Peltigera* was represented in the survey area mainly by *P. dolichorhiza*, which formed large patches over damp soil or litter. In addition to the five species of *Psoroma* listed in table 2, three undetermined species were found.

Several specimens of crustose lichen were found in the survey zones and identified to species level, namely *Dimerella lutea* (Dickson) Trevisan, *Hypocenomyce foveata* Timdal, *Trapelia granulosa* (Hoffm.) V. Wirth and *Thelotrema lepadinum* (Ach.) Ach.

COMPARISON WITH RAINFOREST SURVEY

A comparison between the list of macrolichens from the present survey area and that from a recent survey of the macrolichens of Tasmanian rainforests (Kantvilas *et al.* 1985, Kantvilas & James 1987) shows some striking differences. The total number of taxa found in each of the two surveys is not markedly different: 95 in the present survey and 128 in rainforest. However, only 38 species (listed opposite) were common to the two surveys. The most notable difference is the large number of taxa (32) of *Cladia*, *Cladina* and *Cladonia* on Mount Wellington, compared with only eight species of these genera in rainforests. On the other hand, Mount Wellington tends to be deficient in species of *Menegazzia* (2 v. 14), *Sphaerophorus* (1 v. 9), *Pseudocyphellaria* (6 v. 14) and *Collema* (2 v. 6), compared with rainforest habitats. Differences in the species lists are undoubtedly due to differences in habitat, with rainforest lichens being predominantly epiphytic, whereas the Mount Wellington species are predominantly terricolous.

ACKNOWLEDGEMENT

We thank Dr J.A. Elix of the Australian National University for confirming the identification of *Ramalea cochleata* and for checking several other specimens.

Macrolichen Species found both on Mount Wellington (this survey) and in Rainforest (Kantvilas & James 1987)

Baeomyces arcuatus
Baeomyces heteromorphus
Cladia aggregata
Cladia schizopora
Cladina confusa
(= *C. leptoclada* (des Abb.) D. Galloway)
Cladonia chlorophaea
Cladonia ochrochlora
Cladonia rigida
(= *C. squamosula* Müll. Arg.)
Cladonia scabriuscula
Cladonia subdigitata
Collema laeve
Collema subconveniens
Hypogymnia lugubris
Hypogymnia mundata
Hypogymnia turgidula
Leptogium victorianum
Menegazzia platytrema
Menegazzia subpertusa
Neophyllis melacarpa
(= *Gymnoderma melacarpum* (F. Wilson) Yoshim.)
Parmelia cunninghamii
Parmelia tenuirima
Parmelia salcrambidiocarpa
(previously included in *P. testacea* Stirton)
Parmotrema chinense
(= *Parmelia perlata* (Huds.) Vainio)
Peltigera dolichorhiza
Placopsis gelida
Pseudocyphellaria billardierei
Pseudocyphellaria crocata
Pseudocyphellaria dissimilis
Pseudocyphellaria glabra
(= *P. delisea* (Fée) D. Galloway & P. James)
Pseudocyphellaria rubella
Psoroma asperellum
Psoroma microphyllizans
Psoroma pholidotoides
Psoroma soccatum
Sphaerophorus tener
Stereocaulon ramulosum
Sticta stipitata
Usnea capillacea

REFERENCES

Ahti, T., 1984: The status of *Cladina* as a genus segregated from *Cladonia*. *Beih. Nova Hedwigia* 79: 25–61.

Galloway, D.J., 1985: *FLORA OF NEW ZEALAND, LICHENS*. Government Printer, Wellington, New Zealand.

Kantvilas, G., 1983: A brief history of lichenology in Tasmania. *Pap. Proc. R. Soc. Tasm.* 117: 41–51.

Kantvilas, G. & James, P.W., 1987: The macrolichens of Tasmanian rainforest: key and notes. *Lichenologist* 19: 1–28.

Kantvilas, G., James, P.W. & Jarman, S.J., 1985: Macrolichens in Tasmanian rainforests. *Lichenologist* 17: 67–83.

Martin, D., 1940: The vegetation of Mount Wellington, Tasmania — the plant communities and a census of the plants. *Pap. Proc. R. Soc. Tasm.* (1939): 97–124.

Ratkowsky, D.A. & Ratkowsky, A.V., 1976: Changes in the abundance of the vascular plants of the Mount Wellington Range, Tasmania, following a severe fire. *Pap. Proc. R. Soc. Tasm.* 110: 623–690.

Ratkowsky, D.A. & Ratkowsky, A.V., 1982: The bryophytes of the Mount Wellington Range, Tasmania. *Pap. Proc. R. Soc. Tasm.* 116: 97–115.

Wetmore, C.M., 1963: Catalogue of the lichens of Tasmania. *Rev. Bryol. Lichenol.* 32: 223–264.

Wilson, F.R.M., 1893: Tasmanian lichens. *Pap. Proc. R. Soc. Tasm.* (1892): 133–178.

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A LATE PERMIAN FOSSIL HORSESHOE CRAB (*PALEOLIMULUS*: XIPHOSURA) FROM POATINA, GREAT WESTERN TIERS, TASMANIA

by D. L. Ewington, M. J. Clarke and M. R. Banks

(with one text-figure and one plate)

EWINGTON, D.L., CLARKE, M.J. & BANKS, M.R., 1989 (31:x): A Late Permian fossil horseshoe crab (*Paleolimulus*: Xiphosura) from Poatina, Great Western Tiers, Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 127–131. ISSN 0080-4703. Launceston College, Paterson Street, Launceston, Tasmania 7250 (DLE); Geological Survey of Tasmania, PO Box 56, Rosny Park 7018 (MJC); Geology Department, University of Tasmania, GPO Box 252C, Hobart 7001 (MRB) Australia.

The xiphosuran *Paleolimulus* Dunbar, 1923 is recorded from the Late Permian (Chhidruan) Jackey Shale at Poatina, 41°48'05"S 146°53'06"E. This is the first record of the genus in both Tasmania and the Southern Hemisphere, and extends its distribution to rocks deposited in a high latitude, cold-water environment.
Key Words: Late Permian, cold-water, xiphosuran, Tasmania.

INTRODUCTION

The purpose of this brief communication is to record the discovery of a specimen of the horseshoe crab *Paleolimulus* (Merostomata, Xiphosura) in the Jackey Shale at Poatina. The specimen was found by David Castle, a student at Launceston College, whilst on a geological excursion to Poatina led by the senior author. The specimen was located in the upper part of the Jackey Shale about 3 m below the base of the overlying massive- and cross-bedded, cliff-forming, quartz sandstone of the Ross Formation exposed alongside the Poatina Highway at DP 49055371 (Grid zone 55G Australian Metric Grid), 41°48'05"S 146°53'06"E.

STRATIGRAPHY AND AGE

The Jackey Shale is the lowermost stratigraphic unit of the non-marine Upper Parmeener Supergroup. It conformably overlies the youngest rocks (Bogan Gap Group) of the glacio-marine Lower Parmeener Supergroup and is, in turn, overlain conformably by massive- and cross-bedded, freshwater, quartz sandstone of the Ross Formation. At Poatina, the Bogan Gap Group is essentially unfossiliferous except for worm burrows and other trace fossils, but about 25 km to the southeast, at Lake River, a fauna indicative of the *Echinalosia ovalis* Zone (Late Lymingtonian = Kazanian) occurs close to the Palmer Sandstone (within the lower half of the Bogan Gap Group). Associated microfloras include the palynomorph *Didecitriletes ericianus*, which indicates an age no older than lower Stage 5b of the eastern Australian palynological zonal scheme (Kemp *et al.* 1977). To date, the only macrofossils recorded from the Jackey Shale and correlative beds are the abundant plants *Glossopteris, Gangamopteris, Vertebraria, Phyllotheca* and *Schizoneura*, and these indicate a generalised Late Permian age. Associated microfloras are more definitive, however, and can be assigned to the *Protohaploxypinus microcorpus* Zone of Late Permian (Chhidruan) age (Forsyth 1984). The upper part of the overlying Ross Formation and correlative beds yield vertebrate faunas and both macro- and microfloral assemblages of early Triassic age (Forsyth 1989).

DESCRIPTION

This specimen (UTGD 123979) is the internal mould in siltstone of the carapace of the prosoma and opisthosoma, still connected (fig. 1; plate 1A). The opisthosoma lacks the telson and has no posterior moveable segment. The right-hand side of the prosoma is somewhat laterally compressed at the back. Some grooves in the mould are interpreted as traces of the appendages.

The prosoma is 16.9 mm long (axially), 23.4 mm wide (L:W::0.72:1). (All measurements sagittally

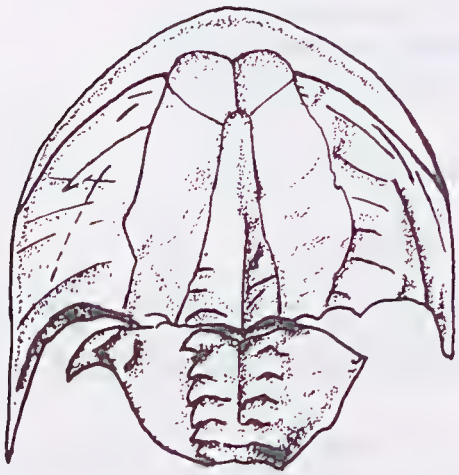

FIG. 1 — Paleolimulus *sp.* × 2.5. *UTGD 123979, Jackey Shale, Upper Permian, Poatina, Tasmania. Drawn by D.M. Banks.*

are taken parallel to the axis and from the intersection of the axis and the anterior margin of the occipital furrow (the reference point, "r.p."), transversely from the axis; the width quoted was obtained by doubling the width of the left-hand, undistorted side.) The margin is uniformly curved in plan and forms a parabola. The outer margin of the genal angle diverges slightly outwards (about 4°) from the general curve of the lateral margin. The posterior margin curves gently forwards to a point 8.2 mm from the axis and 1.1 mm in front of "r.p.". From that point it curves sharply back to form the inner margin of the genal spine. The spine tip is 7.2 mm behind "r.p.", giving a spine length of 8.3 mm. Thus the spine is about 0.49 the axial length of the prosoma. The raised, keeled, cardiac lobe is 6.2 mm wide posteriorly and 11 mm long. The axial furrows converge forward from the posterior margin to about 3 mm in front of "r.p." before becoming slightly convex outwards to a point 7.1 mm in front of "r.p.". For the front 3.4 mm, the cardiac lobe is almost parallel-sided and only 1.25 mm wide. A neck furrow and three, possibly four, furrows are visible in the anteriorly convergent part of this lobe, only the neck furrow being complete. Little can be made of the inter-ophthalmic region. A low, narrow ridge projects forward in the mid-line from the front of the cardiac lobe to meet the re-entrant between the left and right opthalmic ridges. From just behind the front of the cardiac lobe a groove on each side runs anterolaterally to the ophthalmic ridge which it cuts 12mm in front of "r.p.". At the ridge it turns posterolaterally to converge in a gentle curve towards the lateral margin which it meets 8.1 mm in front of "r.p.". This groove defines the posterior edge of the doublure. The ophthalmic ridges differ a little from left to right side because of the deformation. The left-hand ridge commences posteriorly 6.1 mm from "r.p." and runs more-or-less straight forward for 5 mm; then its course is interrupted by a small, outwardly convex bump 1.3 mm long and a little less than 1mm broad, which is probably the compound eye. In front of the bump the ridge runs forward and a little inward to about 3.2 mm in front of the cardiac lobe before curving axially, uniformly and gently to meet the other limb of the ophthalmic ridge 2.5 mm in front of the cardiac lobe. The right-hand ridge is gently convex outwards behind the compound eye but is otherwise similar to that on the left. The fields between the ophthalmic ridges and the lateral margins of the prosoma show structures of two types (plate 1B). The first of these types consist of four grooves, each with a sharp anterior slope and a gentle posterior one. The grooves arise from or close to the ophthalmic ridge, the anterior three just in front of, opposite and just behind the compound eye, the posteriormost one from about halfway between the compound eye and the posterior margin. The front one runs to the sub-marginal groove, almost at right angles to the axis, more posterior ones fanning so that the posteriormost curves outwards and backwards, almost parallel to the inner margin of the genal spine, and ends at about the beginning of the spine. Of these grooves the posterior is the most marked. The description of these grooves is based on the left-hand side, the right not being clear enough. The second type of structure in the area outside the ophthalmic ridges consists of narrow, well-defined grooves gently curved posterolaterally. These originate close to the ophthalmic ridge and run approximately parallel to the margin of the doublure. Successive grooves are progressively longer, the anteriormost being only about 1.1 mm long, the most posterior between three and four times as long and terminating posteriorly close to the hindmost fanning groove. Three, perhaps four, such grooves can be seen, each groove starting axially and anteriorly from the posterior end of the one in front of it and possibly connected to it by a short, linking groove. The overall arrangement appears zigzag. A somewhat similar arrangement on the right-hand side is distorted by deformation. These grooves are interpreted as traces of the

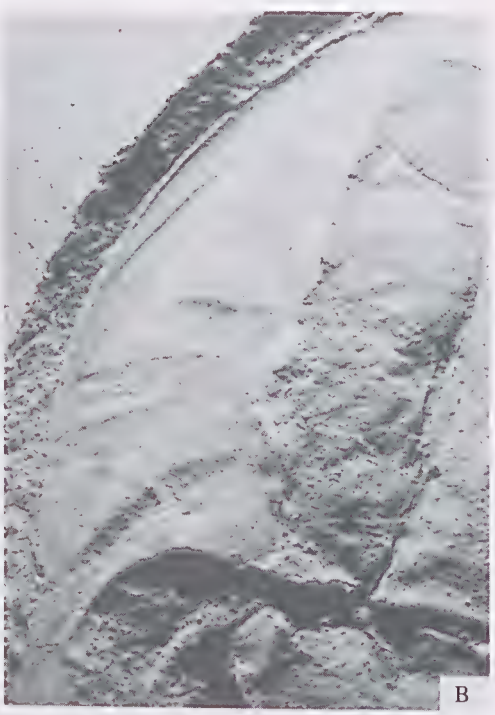

PLATE 1

Paleolimulus *sp.* × *2.5 approx.: (A) the obscure radial markings on the lateral portions of the prosoma represent impressions of the ventral appendages; (B) left-hand side of prosoma showing the impressions of the ventral appendages more clearly.*

appendages. The lateral fields show a submarginal furrow most noticeable anteriorly and anterolaterally. The margin itself has a narrow, low brim representing a shallow groove in the original carapace.

The opisthosoma has a maximum width just behind the front margin of 12.3 mm, i.e. just over half of that of the prosoma, and is 7 mm long, although not all is preserved. The front margin is almost straight in the axial region and remains so on the left-hand side as far out as the base of a spine. On the right-hand side it curves down and back with an angular lateral termination. The lateral margins are smooth, except for the spine and angulation, and gently curved. The opisthosoma is approximately semicircular in outline. On the right-hand side is a low, rather narrow rim and on both sides evidence of a submarginal furrow, broad and shallow. The axis is 6.4 mm wide anteriorly and narrows to about 5 mm at the posterior end, thus being almost parallel sided. Seven pits occur in the axial furrows on each side and, in the case of the second, fifth and sixth, mark the ends of grooves which cross the axis. The other pits have either short or no grooves associated with them. The pits are probably impressions of apodemes. No moveable spines are clearly exposed, unless it be that the left anterior spine is such. This latter spine, however, may be an anterolateral free spine. No moveable segment occurs in the opisthosoma as preserved, nor is the telson preserved.

COMPARISONS

The specimen is comparable in many respects to *Paleolimulus avitus* Dunbar, 1923 from the Lower Permian of North America, and a reasonably confident assignment to that genus, to *Limulitella sensu* Gall, 1971 or a closely related new genus, is warranted. Similarities include the general size and shape, the ophthalmic ridges which meet in front of the cardiac lobe, and the annulated opisthosomal axis. All these features are diagnostic of the family Paleolimulidae Raymond, 1944. The Tasmanian form differs, however, from the North American and some other species in that the prosoma is parabolic, not semicircular, and about twice as long as the opisthosoma, that the interophthalmic region

shows only obscure traces of lobation and that lobation in general is less well developed than in *P. avitus*; also, the ophthalmic ridges extend closer to the anterior margin of the prosoma, which is marked by a well-developed doublure. This latter feature is not evident in *P. avitus* in which, however, its presence may be inferred since it is present in most limuloids. Only one lateral opisthosomal spine is visible on the Tasmanian specimen, which may be an anterolateral free spine. Rather unusually, its opisthosomal axis maintains an almost even width throughout its length, in contrast to the distinct posterior taper in most limuloids. Another North American species, *Paleolimulus signatus* (Beecher), from the Permo-Carboniferous Fort Riley Limestone, Kansas (Dunbar 1923: fig. 8), resembles the Tasmanian form in its anteriorly produced cardiac lobe and ophthalmic ridges but, again, shows well marked lobation in the interophthalmic regions.

Hauschke & Wilde (1987: 88) used the relationship of the inner margin of the genal spine to the lateral margin of the opisthosoma to differentiate *Paleolimulus* from *Limulitella*. The genal spine in *Limulitella* is distinctly triangular, wide anteriorly with a straight inner margin and extending axially as far as the anterolateral corner of the opisthosoma, with the lateral margin of which the inner margin of the genal spine makes an acute angle. In the Tasmanian specimen, the genal spine is less distinctly triangular, has a curved inner margin, is comparatively narrow anteriorly and commences a millimetre or so outside the anterolateral corner of the opisthosoma. On the basis of these characters, this specimen is closer to *Paleolimulus* than to *Limulitella*. It differs from *Limulitella bronni* (Schimper, 1853), type species of *Limulitella* Stormer, 1952 in the outline of the prosoma, in the width, shape and axial extent of the genal spine and in the relative lengths of the prosoma and opisthosoma. Further, the opisthosoma of *Limulitella* has lateral margins with indentations not evident in the Tasmanian specimen (*pace* Gall 1971). In view of these differences from *P. avitus* on the one hand and *Limulitella* on the other, the Tasmanian material may well be a new genus, but the authors consider it inadvisable to base a new genus on a single, incomplete, internal mould.

Dubbolimulus peetae Pickett, 1984, from the Middle Triassic of the Sydney Basin, New South Wales, is broadly similar in size and shape, but the prosoma is proportionately shorter and wider, the pre-ocular ridges do not meet in front of the cardiac lobe, the eyes are more posteriorly placed, the opisthosoma lacks lateral spines, and the opisthosomal axis is not annulated. The present authors do not agree with the synonymy of *Dubbolimulus* and *Paleolimulus* as advocated by Hauschke & Wilde (1987). *Austrolimulus fletcheri* Riek, 1955, also from the Triassic of the Sydney Basin, with its long, laterally directed genal spines and other features, is quite distinct.

SIGNIFICANCE

Fossil Upper Palaeozoic (and other) xiphosurans are generally rare. They are mostly known from warm-climate, non-marine Upper Carboniferous coal measure sequences in Europe, and Permian rocks in North America. The present Tasmanian example, the first record of the genus *Paleolimulus* from the Southern Hemisphere, is from rocks deposited in a freshwater, fluvial environment, and thus extends the distribution of the genus to high-latitude (75–80°S), cold-climate regimes which then prevailed, following the severe Late Palaeozoic glaciation of the Tasmanian region and elsewhere in Gondwana. The other undoubted Australian xiphosurans are *Austrolimulus* and *Dubbolimulus*, both from the Triassic of the Sydney Basin, New South Wales, and *Victalimulus* from the Lower Cretaceous of Victoria (Riek & Gill 1971). *Pincombella belmontensis* Chapman, 1932, previously recorded as the sole Permian xiphosuran from Australia, is an incomplete hemipteran insect (Pickett 1984).

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REFERENCES

Chapman, F., 1932: Two new Australian fossil king-crabs. *Proc. R. Soc. Vict.* N.S. 44: 100–102.

Dunbar, C.A., 1923: Kansas Permian insects. Part 2. *Paleolimulus*, a new genus of Paleozoic Xiphosura, with notes on other genera. *Am. J. Sci.* Ser. 5(5): 443–454.

Forsyth, S.M., 1984: Oatlands. *Geol. Atlas 1:50 000 ser. Explan. Rep.* Zone 7, Sheet 68 (8313S). Tasm. Dep. Mines.: 1–182.

FORSYTH, S.M., 1989: Upper Parmeener Supergroup. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 309–335.

GALL, J.C., 1971: Faunes et paysages du grès à *Voltzia* du Nord des Vosges. Essai paléoécologique sur le Bundsandstein Superieur. *Mem. Serv. Carte. geol. Als. Lorr.* 34: 35–36.

HAUSCHKE, N. & WILDE, V., 1987: *Paleolimulus fuchsbergensis* (Xiphosura, Merostomata) aus der oberen Trias von Nordwestdeutschland, mit einer Ubersicht zur Systematik und Verbreitung rezenter Limuliden. *Palaeont. Z.* 61: 87–108.

KEMP, E.M., BALME, B.E., HELBY, R.J., KYLE, R.A., PLAYFORD, G.E. & PRICE, P.L., 1977: Carboniferous and Permian palynostratigraphy in Australia and Antarctica. *B.M.R. J. Aust. Geol. Geophys.* 2: 177–208.

PICKETT, J.W., 1984. A new freshwater limuloid from the Middle Triassic of New South Wales. *Palaeontology* 27: 609–621.

RAYMOND, P.E., 1944: Late Paleozoic Xiphosurans. *Bull. Mus. comp. Zool. Harv.* 94: 475–508.

RIEK, E.F., 1955: A new xiphosuran from the Triassic sediments at Brookvale, New South Wales. *Rec. Aust. Mus.* 23: 281–282.

RIEK, E.F. & GILL, E.D., 1971: A new xiphosuran genus from Lower Cretaceous freshwater sediments at Koonwarra, Victoria, Australia. *Palaeontology* 14: 206–210.

(accepted 12 May 1989)

A RE-EXAMINATION OF *DITHYRIDIUM CYNOCEPHALI* RANSOM 1905, A METACESTODE PARASITE FROM THE THYLACINE *THYLACINUS CYNOCEPHALUS*

by David L. Obendorf and Steven J. Smith

(with one table and one plate)

OBENDORF, D.L. & SMITH, S.J., 1989 (31:x): A re-examination of *Dithyridium cynocephali* Ransom 1905, a metacestode parasite from the thylacine *Thylacinus cynocephalus*. *Pap. Proc. R. Soc. Tasm.* 123: 133–136. ISSN 0080–4703. Tasmanian Department of Agriculture, PO Box 46, Kings Meadows, Tasmania 7249 (DLO); and Tasmanian Department of Lands, Parks & Wildlife, GPO Box 44A, Hobart, Australia 7001 (SJS).

Re-examination of *Dithyridium cynocephali* Ransom 1905, a metacestode parasite from the thylacine *Thylacinus cynocephalus*, has revealed it to be morphologically indistinguishable from metacestodes of the tapeworm *Anoplotaenia dasyuri* found in the eastern quoll *Dasyurus viverrinus* and the spotted-tailed quoll *D. maculatus*, in Bennett's wallaby *Macropus rufogriseus rufogriseus* and in the Tasmanian pademelon *Thylogale billardierii*. The Tasmanian devil *Sarcophilus harrisii* is the predominant definitive host for *A. dasyuri*, but the two quoll species can also serve as definitive hosts. It is considered likely that quolls may act as intermediate hosts through the occasional consumption of Tasmanian devil faeces containing infective *A. dasyuri* eggs. The thylacine may have become infected with *A. dasyuri* in a similar manner, by engaging in coprophagy in the wild or in captivity.
Key Words: thylacine, *Anoplotaenia dasyuri*, metacestodes, coprophagy, *Dithyridium cynocephali*.

INTRODUCTION

On 4 November 1904, a mature female thylacine *Thylacinus cynocephalus* died at the National Zoological Park in Washington, D.C., U.S.A. At the necropsy performed at the National Museum "... encysted larval forms of a tapeworm were found in all the muscular structures of the body". Ransom (1905) published a brief report of the larval cestode recovered from the heart and skeletal muscles of the animal and named the parasite *Dithyridium cynocephali*. Fortunately, specimens of the parasite were also lodged in the National Parasite Collection (NPC) of the United States Department of Agriculture. When metacestodes were recently found in the heart and skeletal muscles of eastern quolls *Dasyurus viverrinus* and spotted-tailed quolls *D. maculatus* from Tasmania's northwestern highlands, a re-examination of the parasite from the thylacine was undertaken. The only other parasites recorded from the thylacine are the endemic Tasmanian flea *Uropsylla tasmanica* (Dunnet & Mardon 1974) and the ascaridoid nematode *Ascaridia columbae* (Sprent 1972).

MATERIALS AND METHODS

For this study, the original slides of serial-sectioned *Dithyridium cynocephali* (NPC No.3888) and several additional sections prepared at Mount Pleasant Laboratories, Launceston, from alcohol-preserved specimens were examined. These specimens were compared with metacestodes obtained from the hearts of naturally-infected Bennett's wallabies *Macropus rufogriseus rufogriseus* and Tasmanian pademelons *Thylogale billardierii*. Metacestodes recovered from two eastern quolls *Dasyurus viverrinus* and four spotted-tailed quolls *D. maculatus* from the Cradle Mountain region were also examined. In addition to this material, a metacestode found in masseter muscle from an alcohol-preserved thylacine skull (NMV C5752) from the Museum of Victoria was also examined.

All preserved specimens and muscle tissues were prepared for microscopic examination using routine histological techniques. Specimens were dehydrated through increasing concentrations of ethyl alcohol, paraffin embedded and sectioned at a thickness of 5 µm. Sections were placed on glass slides, stained with haematoxylin and eosin, and examined with a light microscope. Measurements of various parts of the metacestodes were taken using an ocular micrometer.

Histological sections of metacestodes from eastern quoll, spotted-tailed quoll and thylacine have been lodged on slides in the Australian Helminth Collection (AHV18680, AHC18681, AHC18682 & AHC18683). Samples of preserved

infected muscle tissue from thylacine and spotted-tailed quoll have been lodged in the same collection (AHC18684 & AHC18685).

RESULTS AND DISCUSSION

Although somewhat faded, the original mounted specimens from the thylacine (NPC No.3888) had sufficient clarity and contrast for proper examination. Freshly-prepared sections of metacestodes from this thylacine stained more intensely, but the age of the specimens caused the differential staining properties of the haematoxylin and eosin dyes to be suboptimal.

The metacestodes from the thylacine were morphologically indistinguishable from those recovered from two extant dasyurids *D. viverrinus* and *D. maculatus*, and two macropods *M. r. rufogriseus* and *T. billardierii*. In all hosts, metacestodes were circular to ovoid and were contained within a fibrous connective tissue capsule produced by the host tissues. In skeletal muscle tissues they were generally aligned with muscle fibres, and fat tissue was present at each pole of the outer fibrous capsule. They had a thick cuticle or tegument and an underlying muscle system; numerous cell bodies were arranged in a dense aggregate under the cuticle, adjacent to the muscles. The body of the parasite consisted of open parenchyma in which cell nuclei were scattered; a distinctive characteristic of the parenchyma was the presence of numerous calcareous corpuscles. The scolex was unarmed and invaginated into the body of the metacestode, the invaginated portion being lined by cuticle and containing four suckers. The cuticle in these areas was very thick and overlaid large numbers of cell nuclei. In some specimens from all hosts a small bladder or vesicle was seen in the posterior pole of the metacestode; several showed an osmoregulatory canal consisting of a tubular invagination lined with cuticle and measuring 80 to 210 µm in length. The dimensions of the whole metacestode, the suckers and the cuticle thickness of various specimens from the thylacine (NPC No.3888), the two quoll species and the two macropods are presented in table 1.

The metacestodes recovered from the two macropods are typical of the intermediate host stage of the tapeworm *Anoplotaenia dasyuri*. All those examined and described in this study are similar to *A. dasyuri* metacestodes originally described from experimentally infected mice (Beveridge *et al.* 1975) and to those from naturally infected Tasmanian marsupials (Gregory *et al.* 1975). The only difference in the description of metacestodes from experimentally and naturally infected marsupials was the absence of a posterior bladder or vesicle in metacestodes from the laboratory mice. This difference was not considered significant, as the feature also appeared to be variable in specimens from naturally infected hosts.

Ransom (1905), in his original report, considered that the larval cestodes in the thylacine were probably derived from a comparatively recent infection acquired through ingestion of infective tapeworm eggs at the Zoological Park in Washington. Re-examination of this museum material and its comparison with metacestode infections of *A. dasyuri* in *M. r. rufogriseus* and

TABLE 1

Dimensions of the Metacestodes from Various Hosts

Host	Metacestode*		Suckers*		Cuticle
	length mm	width mm	length mm	width mm	thickness* mm
Thylacinus cynocephalus	652 (430–880)	343 (220–380)	162 (107–182)	113 (90–164)	5 (3.8–6.5)
Dasyurus spp.	654 (400–930)	349 (230–460)	148 (139–165)	109 (78–139)	4.5 (3.2–5.5)
Macropus r. rufogriseus *Thylogale billardierii*	487 (370–560)	266 (215–315)	138 (115–150)	66 (60–75)	5.5 (4.1–6.2)

*Mean measurements of ten specimens, range in parenthesis.

T. billardierii suggest that the parasite reported from this captive thylacine is almost certainly the endemic Tasmanian parasite *A. dasyuri* (pl. 1). At the time of the recovery of this parasite from the thylacine and its subsequent naming by Ransom (1905), *A. dasyuri* was unknown and its indirect life cycle was not elucidated until relatively recently (Gregory *et al.* 1975).

Anoplotaenia dasyuri is an abundant parasite in Tasmania, maintained through a carnivore-carrion feeding association involving the Tasmanian devil *Sarcophilus harrisii* as definitive host and certain macropod species as intermediate hosts (Gregory *et al.* 1975). Adult tapeworms occur in the small intestines of Tasmanian devils, and metacestode stages are found in the hearts, lungs and skeletal muscles of macropods, principally *M. r. rufogriseus* and *T. billardierii*. These herbivorous macropods acquire infection through the ingestion of herbage containing infective *Anoplotaenia* eggs. The prevalence of *A. dasyuri* infection in Tasmanian devils is very high: 99% (293 of 294) in one survey (Gregory *et al.* 1975) and 98% (87 of 88) in another carried out by one of the authors (DLO) in 1988. In addition, the large numbers of gravid tapeworms found in Tasmanian devils, the relatively short prepatent period (less than 85 days — Gregory *et al.* 1975) and the high density of Tasmanian devils in many areas of Tasmania (Green 1968, Guiler 1970) ensure a widespread distribution of eggs in the environment and a high level of exposure to infection for the intermediate hosts.

Tasmanian devils are the predominant definitive hosts of *A. dasyuri*, but both *D. viverrinus* and *D. maculatus* are also known to harbour small numbers of immature and sometimes gravid worms (Gregory *et al.* 1975, DLO, unpubl. observations). Differences between the feeding habits of quolls and Tasmanian devils are likely to reduce the exposure of quolls to adult *A. dasyuri* infection. Eastern quolls eat insects in large quantities when available, but also prey on ground-nesting birds and small mammals. Spotted-tailed quolls are opportunistic predators of a variety of birds, rodents, other arboreal and terrestrial small mammals, reptiles and invertebrates. Both species of quoll will scavenge carrion of large mammals, but Tasmanian devils are thought to be more successful scavengers for any that is available (Strahan 1983).

The finding of numerous metacestodes of *A. dasyuri* in both species of quoll in the Cradle Mountain region was unexpected; it seems likely that they are accidental intermediate hosts of *A. dasyuri*. Access to infective *Anoplotaenia* eggs could occur if quolls consumed either herbage containing eggs or the faeces of the Tasmanian devil; the relatively high levels of infection by metacestodes indicate that the latter is more likely. Another possibility for transmission to the quolls is that invertebrates (such as insects and earthworms), associated with soil, herbage or faeces, are involved as mechanical vectors of *Anoplotaenia* eggs. *Anoplotaenia dasyuri* has not, however, been recorded in the two species of bandicoot in Tasmania, *Perameles gunnii* and *Isoodon obesulus*, both of which eat large quantities of these invertebrates.

All of the quolls with metacestode infections were old or injured, with worn or missing teeth, foot injuries or arthritic problems; such debilitated individuals are likely to be less successful predators and carrion feeders. This factor, combined with the

PLATE 1

Photomicrograph of an encysted metacestode dissected from the skeletal muscles of Thylacinus cynocephalus *(NPC No. 3888).*
C = cuticle, S = suckers, V = vesicle, OC = osmoregulatory canal, IS = invaginated scolex. Scale bar = 0.1 mm.

winter depletions in food availability (absence of insects and migration of many species of birds) in the highlands, may occasionally force these quolls to adopt coprophagic feeding habits. It is conceivable also that the thylacine held in captivity in the USA may have acquired its infection in Tasmania prior to capture or through close contact with devils whilst held in zoos either in Tasmania or the USA. In the case of the thylacine specimen from the Museum of Victoria (NMV C5752), the original correspondence accompanying this material confirms that the animal was shot in the wild. The discovery of a free-ranging thylacine with metacestode infection suggests that this large carnivorous marsupial was capable of acting as an intermediate host for *A. dasyuri*, as do the quolls today.

It is not known whether the thylacine was capable of harbouring adult infections of *A. dasyuri*. The preserved stomach and intestines of four thylacines held at the Australian Academy of Science in Canberra were examined by Sprent (1971). No intestinal cestodes were found. Subsequent enquiries made by Sprent failed to find any further parasites in museum collections in Europe, the USA and Australia.

Maintenance of *A. dasyuri* in Tasmania has relied on successful co-evolution of the parasite within a natural carnivore–herbivore feeding association. Little information on the dietary preferences of free-ranging thylacines is available (Smith 1980, Guiler 1985, Dixon 1989). However, one might suspect that a close "predator–prey" relationship existed between thylacines and native macropods similart to that between Tasmanian devils and macropods. The results of this study, however, suggest that the thylacine differs from the Tasmanian devil in that the former is capable of sustaining metacestode infections of *A. dasyuri*, whilst no such larval stage infections have been reported in the latter. In this respect, the host–parasite relationship between the thylacine and *A. dasyuri* is similar to that occurring with the two species of quoll. This observation may suggest that the thylacine was not an important definitive host of *A. dasyuri*.

The metacestodes of *Dithyridium cynocephali* and *Anoplotaenia dasyuri* are indistinguishable and the parasites are probably the same species. There are many cestode species, however, that have obviously different adults but indistinguishable metacestodes. The authors have not formally suppressed either of the scientific names, as it cannot be experimentally demonstrated that the adult of the cestode in the thylacine and in the spotted-tailed quoll are the same.

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REFERENCES

Beveridge, I., Rickard, M.D., Gregory, G.G. & Munday, B.L., 1975: Studies on *Anoplotaenia dasyuri* Beddard 1911 (Cestoda:Taeniidae), a parasite of the Tasmanian devil: Observations on the egg and metacestode. *Int. J. Parasitol.* 5: 257–267.

Dixon, J.M., 1989: Thylacinidae. In *FAUNA OF AUSTRALIA*, Vol.I(b). Bureau of Flora and Fauna, Canberra: chapter 20.

Gregory, G.G., Munday, B.L., Beveridge, I. & Rickard, M.D., 1975: Studies on *Anoplotaenia dasyuri* Beddard 1911 (Cestoda:Taeniidae), a parasite of the Tasmanian Devil: Life cycle and epidemiology. *Int. J. Parasitol.* 5: 187–191.

Dunnet, G.M. & Mardon, D.K., 1974: A monograph of Australian fleas (Siphonaptera). *Aust. J. Zool.* Suppl. Ser. No.30.

Green, R.H., 1968: Notes on the Devil (*Sarcophilus harrisii*) and the quoll (*Dasyurus viverrinus*) in North-eastern Tasmania. *Rec. Q. Vict. Mus.* 27: 1–13.

Guiler, E.R., 1970: Observations on the Tasmanian Devil, *Sarcophilus harrisii* (Marsupalia:Dasyuridae) I. Numbers, home range, movements and food in two populations. *Aust. J. Zool.* 18: 49–62.

Guiler, E.R., 1985: *THYLACINE: THE TRAGEDY OF THE TASMANIAN TIGER*. Oxford University Press, Melbourne.

Ransom, B.H., 1905: Tapeworm cysts (*Dithyridium cynocephali* n.sp.) in the muscles of the Tasmanian Wolf (*Thylacinus cynocephalus*). *Am. Microscop. Soc. Trans.* 27: 31–32.

Smith, S.J., 1980: The Tasmanian Tiger. *Wildl. Division Tech. Rep.* 81/1. Tasm. NPWS.

Sprent, J.F.A., 1971: A new genus and species of Ascaridoid nematode from the marsupial wolf (*Thylacinus cynocephalus*). *Parasitology* 63: 37–43.

Sprent, J.F.A., 1972: *Cotylascaris thylacini*, a synonym of *Ascaridia columbae*. *Parasitology* 64(2): 331–332.

Strahan, R.E., 1983: *COMPLETE BOOK OF AUSTRALIAN MAMMALS*. The Australian Museum, Angus & Robertson, Sydney.

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A HISTORY OF DISCOVERY, STUDY AND EXPLOITATION OF COAL IN TASMANIA

by Carol A. Bacon and Maxwell R. Banks

(with four tables, ten text-figures and three appendices)

BACON, C.A. & BANKS, M.R., 1989 (31:x): A history of discovery, study and exploitation of coal in Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 137–189. ISSN 0080–4703. Department of Mines, PO Box 56, Rosny Park, Tasmania 7018 and Department of Geology, University of Tasmania, GPO Box 252C, Hobart, Tasmania 7001, Australia.

The history of discovery of coal in Tasmania, the history of geological work on the coal and the history and methods of exploitation of the coal have been influenced by three main factors: (1) population spread and density, (2) geology, including quality, of coal and (3) economic conditions. The pattern of discovery showed the effects of population growth and the spread of settlement in the island and, particularly in the early days of the colony, the types of discoverers reflected important groups in the population. Study of the coal was, for the greater part of last century, carried out by visiting naturalists, amateurs (some of them gifted) or overseas experts. Even when this situation changed and the work was done by resident geologists, the study usually depended on concepts and practices developed elsewhere. The derivative nature of this work is a reflection of the generally poor quality of known coals and, by and large, low known coal reserves. The history of mining reflects the geology of the coal deposits, changes in the means and availability of transport and, in general, economic conditions. Coal mining had significant effects on only two Tasmanian communities. The discovery and quality of coal in the Don and Mersey Valleys attracted many people to the area in the 1850's and early 1860's but the prevalence of faults and thinness of seams precluded later significant developments. The opening of the railway to the eastern end of the South Esk valley in 1886 improved the ease and reduced the cost of transportation, and thus led to increased demand for production of coals from the Fingal-St Marys area. The opening initiated a long period during which coal mining made a significant impact on the economy of that area. The thick and relatively unfaulted seams there allowed economic mining until the low oil prices of the 1960's combined with the relatively low quality and total reserves of coal to force closures of mines, which severely disturbed the communities of Fingal and St Marys.

Key Words: Tasmania, coal, coal mining, coal discovery.

INTRODUCTION

Now that the intense activity in exploring for coal which affected Tasmania in the past decade has subsided, it seems an appropriate time for contemplation, for looking back at the discoveries of coal and those who made them, at the investigation of the coal, and at the history and effects of coal mining in the State. The recent period of intense exploratory activity was not the first; that occurred in a period, about a quarter of a century, beginning with the discovery of coal at Saltwater River in 1833. A second period of intense activity, near the turn of the century, followed the development of rail transport, when the emphasis was on the expansion of mining in the South Esk Valley.

As with the recent activity so also with this history — it is not the first. The Coal Resources Bulletin (Hills *et al.* 1922) dealt in passing with some historical aspects. A more systematic but also incomplete treatment was provided by Besford in 1958 to be followed by one (Booth 1962) with a very different emphasis from earlier ones and from this present one.

GENERAL BACKGROUND

Coal has been used as a fuel in Britain for almost two millenia and in southern Europe for rather more than that. Its importance as a source of heat and a reducing agent has guaranteed State and private interest in it for many centuries. Coal was dug on the shores of the Firth of Forth about AD 1200 (Cantrill 1914: 4 *et seq.*) and in Northumberland and Durham in the reign of Henry III (first half of thirteenth century). By the middle of the 14th century, coal was mined in pits and raised by windlasses. Boring to prove coal before mining began in northern England early in the 17th century. As early as 1719 Strachey demonstrated the stratigraphy and structure of a coalfield south of Bristol (Strachey 1719). In the year following

the white settlement of Australia, a remarkably complete description of coal-bearing sequences in Great Britain was published (Williams 1789 quoted in Zittel 1901: 109). A treatise dated 1708 described methods of coal mining, which was then the "bord-and-pillar" system (Cantrill 1914: 14). Longwall mining, as opposed to bord-and-pillar, did not become common until the last decade of the 18th century. In the 1730's coke, derived from coal, was first used in the smelting of iron, the practice starting at Coalbrookdale in Shropshire (Cantrill 1914: 20). By the end of the 18th century, when exploration of Tasmania was intensifying, and a little later, after settlement began, coal was widely used in Britain not only as a source of heat but in smelting, as the source of the reducing agent.

It was thus well known by the time of the settlement of Tasmania that coal was economically important. Much was known of the geology of coal in Britain and western Europe, and the importance of the number and thickness of seams in a locality, the dip of the seams, the associated rocks, the presence of faulting and the quality (heat capacity, calorific value, specific energy) were well understood. It is no accident that the first discoverer of coal in Tasmania noted the thickness, dip and associated rocks.

Had there been thick seams of coal readily accessible to the new settlements on the Derwent and Tamar, less timber close at hand as a source of fuel or greater populations, the rate of discovery of coal might have been higher and the first serious attempt at mining might have occurred much earlier than it did, i.e. 30 years after settlement began.

In this paper, we want to look at who discovered coal in Tasmania, where and when. The discoveries were not random. We will explore the way in which geological information on the coal accumulated and changed. There is a suggestion that in too many cases the possible effects of geological conditions on the mining of coal have been ignored. Mining methods have been influenced by the geology of the coal measures and the topography of the State. The intensity of mining, governed by technological and economic factors outside the coal industry and, on some occasions, outside Tasmania, has been variable; the success rate has been low.

Apart from the sources included in the list of references, material has been drawn from records held in Tasmanian State Archives and some other records. A list of these will be found after the reference list.

DISCOVERIES AND DISCOVERERS

Even before David Collins reached the Derwent to found Hobart Town early in 1804, coal had been discovered twice in Tasmania. The first discovery was made by French naturalist Labillardière in February 1793 in the cliffs lining what is now called South Cape Bay. Labillardière reported

> "... the side of the mountains being exposed for a considerable extent we observed a horizontal vein of coal the greatest thickness of which did not exceed one decimetre. We noticed it for a space of more than 300 m. The stratum below it was sandstone and above it a dark shale. From these indications I presume that excellent coal may be found in abundance at greater depth. It is well known that the richest mines of this fuel are commonly found below sandstone ..." (translated from Labillardière 1800, Vol. 2: 22).

Labillardière was the naturalist with the D'Entrecasteaux Expedition returning from the unsuccessful expedition into the Pacific in a search for La Pérouse. He had studied botany at Montpelier and had a medical degree from Paris (*Australian Dictionary of Biography* (*ADB*) Vol. 2, 1967: 69). It is likely that the studies for his degree included some readings in natural philosophy, including geology.

On 8 November 1803, James Meehan discovered coal in a "high rocky bank" beside the Coal River just downstream from what is now Richmond and marked his map "coal here". James Meehan had been sent on an exploratory expedition from Risdon Cove by Lieut. John Bowen, the Commandant of this first European settlement on the Derwent River. Earlier, Meehan, transported at age 24 for his part in the Irish Rebellion of 1798 and assigned as servant to Charles Grimes, Acting Surveyor General of New South Wales, had accompanied Lieut. Robbins as a "kind of mineralogist" (HRNSW V: 136) during a survey of King Island late in 1802.

Captain James Kelly discovered brown coal on the northern shore of Macquarie Harbour in 1815 and his report was promptly followed up by a visit by Mr Denis McCarty who reported

> "... a quantity of coal ... an immense bed ... the bank from the river was nearly all coal in strata 6 ft [1.8 m] thick then a few feet strata of clay then coal again ..." (*Hobart Town Gazette* 15 June 1816).

Captain Kelly later (1820) reported the existence of three seams of coal at Macquarie Harbour (HRA III

(3): 466). James Kelly was born in Parramatta, NSW, in 1791, made several voyages before he was 13 and had become a master mariner by 1812. He was later well-known as an entrepreneur in Hobart (Pretyman 1967).

Later discoveries (or first reports of discoveries) and discoverers are tabulated as appendix 1.

Of the discoverers, Joseph Milligan and Charles Gould play significant roles in understanding the geology of Tasmanian coal, and their contribution will be dealt with at greater length in the next section. The other discoverers seem to have had a variety of professions and occupations. Only surveyors seem to be better represented than others. The role of James Meehan has already been noted. Other surveyors were George Woodward and James Hughes who discovered coal at Saltwater River; like Meehan, they were former convicts. Woodward acted as a surveyor in Hobart from 1826 to 1831 and was then convicted on a forgery charge. Hughes was transported for seven years for obtaining 15 plants by false pretences (Heard 1981:248). From 6 March 1833 to December 1833 he was employed at a shilling a day to make a survey of the Tasman and Forestier Peninsulas, a task completed on 24 August 1833. Other convicts who discovered coal were Jesse and Isaac Garland and Zephaniah Williams, of whom more later. Burgess, also a contract surveyor, who found coal in 1852 at Coal Hill, was one of the early explorers in western Tasmania. That surveyors were prominent as a group among the discoverers of coal comes as no surprise, since their training included studies on natural productions including minerals and rocks, and the practice of their profession commonly involved work in sparsely populated and poorly explored areas.

Of the discoveries prior to 1840, many were in coastal situations and some of the rest in cliff sections by streams. Subsequent discoveries were predominantly inland but even then many were in river or creek sections. The locales of the discoveries, i.e. mainly in marine or river cliffs or in stream beds, are readily explicable as only in such situations do coal seams normally crop out noticeably.

When the sites of discoveries and first reports are plotted on maps for successive time periods, relationships emerge between the distribution of sites on the one hand and early maritime exploration or the spread of settlement on the other. Thus, discoveries prior to and including 1820 (fig. 1A) were in coastal or estuarine cliffs, plus one in a river bank section seen on the first inland exploration and one doubtfully of this period in the bank of a branch of the Coal River above Colebrook some kilometres beyond settlement in that valley. The few known discoveries in the decade to 1830 were close to Hobart Town and on the Huon River (fig. 1B). Subsequent discoveries were made in several coastal sections, up the Derwent Valley well within the limit of settlement at the time (cf. Plomley 1971: map 2 as amended) and within the Van Diemen's Land Company (VDL Co.) area (fig. 1C). The map for the 1841–50 decade (fig. 1D) shows distinct correlation with Plomley's map as amended (1971) and the extent of land alienation in 1854 (Scott 1965: map 8). On the other hand, coal discovery localities and timing are, after an initial period, poorly related to the process of exploration (cf. maps herein, with Maude 1965: figs 32–33). Discoveries in the next decade show a concentration in the newly inhabited Mersey and Don areas, with an isolated discovery arising during the early stages of probing into western Tasmania (fig. 1E). As settlement spread in the Huon district, coal discoveries followed (figs. 1F to 1I and Scott 1965: map 8). Discovery of tin at Mt Bischoff in 1871 led initially to discoveries of lignite nearby (fig. 1G) and then to discoveries of black coal and lignite further away in the Central Highlands and in western Tasmania (figs. 1H to 1I), e.g. south of Zeehan. Thus, from 1793 to about 1910 the discovery of coal was connected with maritime (initially) and inland (later) exploration and with the spread of settlement. Blainey (1961: 344–345) noted the importance of accessibility in the pattern of spread of gold discoveries. This factor was also important in the distribution of coal discoveries in Tasmania.

The pattern of discoveries through time is not random (fig. 2A(ii), B(ii)). The rate of discovery was slow and increased slowly until 1833 (the discovery at Saltwater River). Thereafter the rate increased to such an extent that the *Cornwall Chronicle* of 2 April 1851 was able to comment, in reporting the discovery of coal on the Don River a few weeks before, that "the discovery of coal lately in this island has become a sort of mania". Subsequently the rate slowed down but reached a second but lower peak in the 1881–90 decade, followed by a further deceleration, with a third peak, lower again, between 1921 and 1930, and finally a further, even lower peak in the 1951 to 1960 decade. It is interesting to note the parallelism in the rise of population of the island (fig. 2A(i)) and the increase in number of coal discoveries (fig. 2A(ii)), also fig. 2B(i) and (ii). These two parameters varied sympathetically until 1930, after which the rate of coal discovery dropped

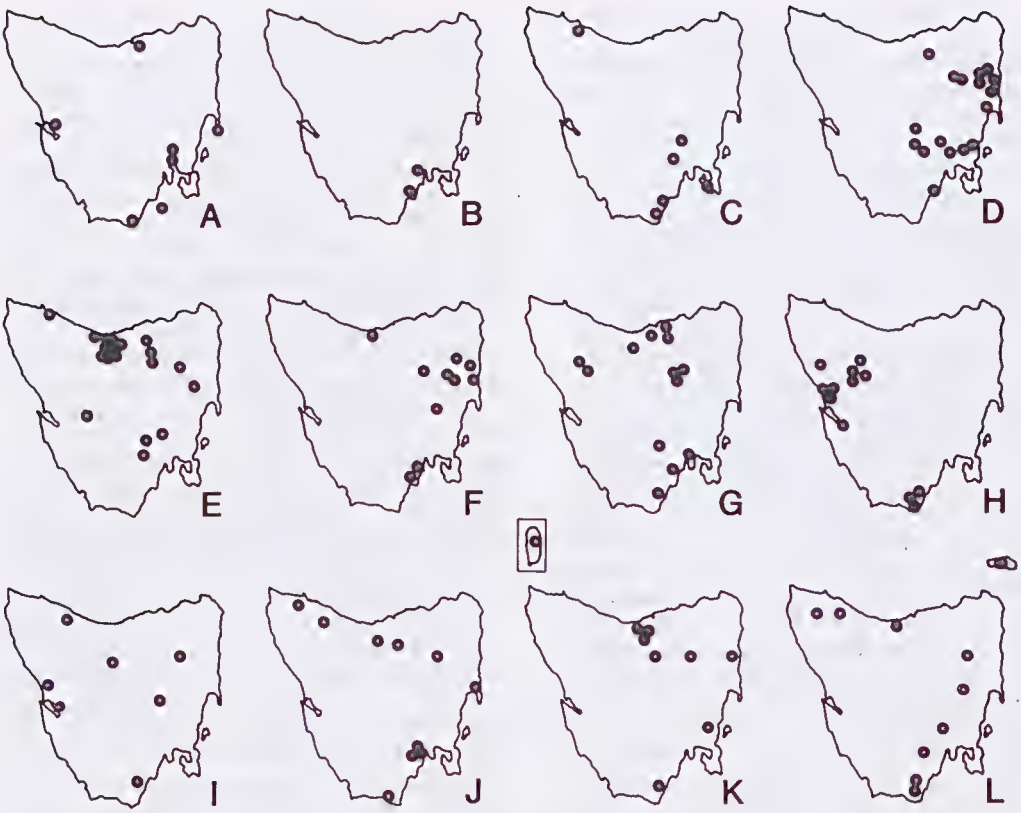
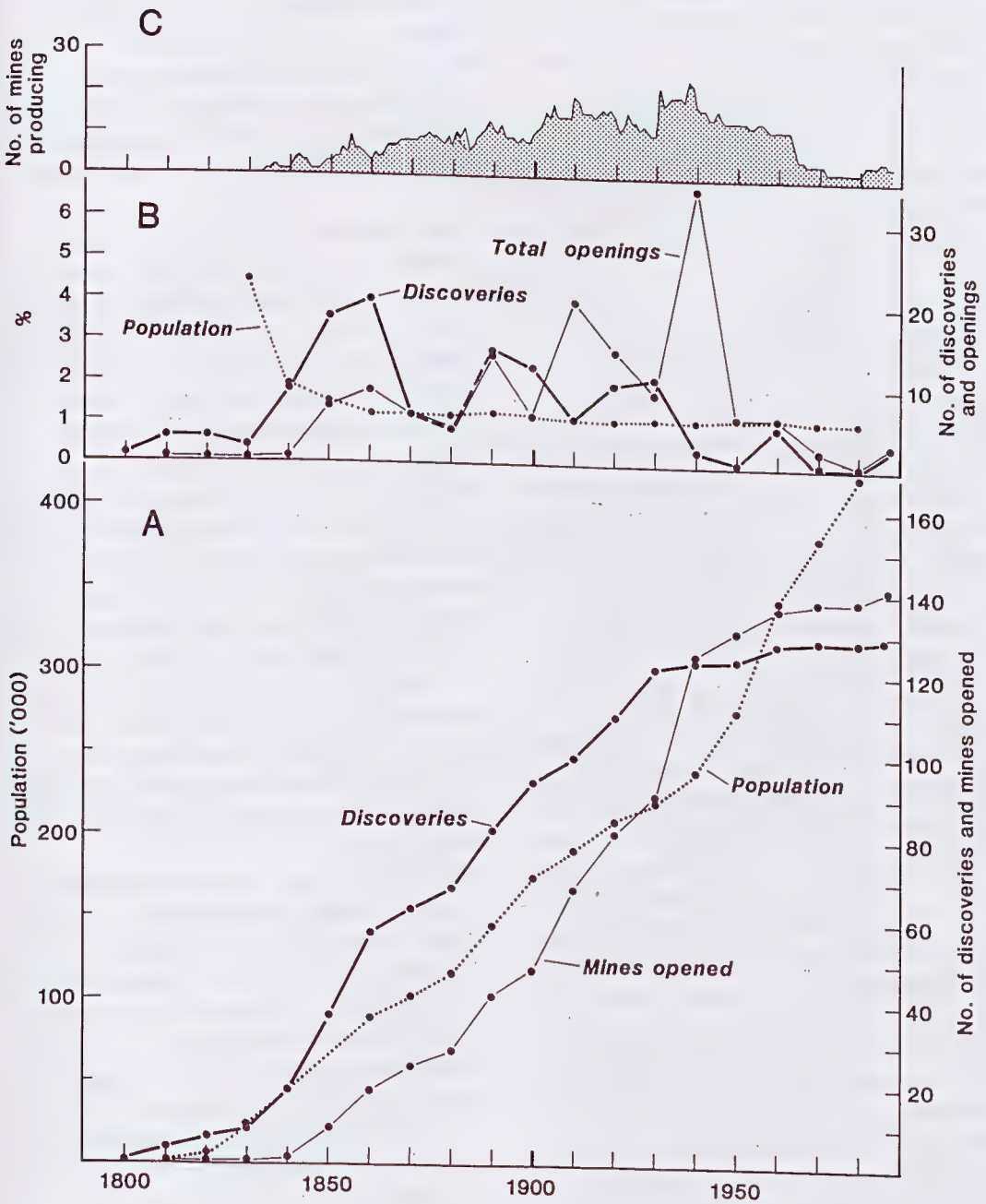


FIG. 1 — Geographical distribution of coal discoveries in Tasmania in successive periods: (A) pre-1820, (B) 1821–30, (C) 1831–40, (D) 1841–50, (E) 1851–60, (F) 1861–80, (G) 1881–90, (H) 1891–1900, (I) 1901–10, (J) 1911–20, (K) 1921–30, (L) post-1930.

FIG. 2 (opposite)— (A)(i) increase in population of Tasmania (mainly after Tasmanian Year Book 1975*: 158); (ii) total number of discoveries of coal made or reported in Tasmania in successive decades, e.g. 1811–20, 1821–30 ... ; (iii) progressive total of mine openings at end of successive decades (from Department of Mines production records).*
(B)(i) curve showing rate of increase of population of Tasmania, decade by decade (points on curve calculated by dividing population at end of one decade (say 1930) by population at end of previous decade (say 1920) (from Tasmanian Year Book 1975*: 158); (ii) number of discoveries of coal in successive decades (based on appendix 1); (iii) number of openings of coal mines in successive decades (number of re-openings in each decade noted); based on details in appendix 2.*
(C) number of mines producing each year.


C
No. of mines producing
30
0
B
%
6
5
4
3
2
1
0
Total openings
Discoveries
Population
30
20
10
No. of discoveries and openings
A
Population ('000)
400
300
200
100
160
140
120
100
80
60
40
20
Discoveries
Population
Mines opened
No. of discoveries and mines opened
1800
1850
1900
1950

drastically. The slowing in the rate of discovery is probably a reflection of the fact that most of the onshore areas likely to contain coal had been explored by that time (the graph — fig. 2A(ii) — takes no cognisance of coals discovered at depth offshore in the last couple of decades).

Some of the causes of at least the first two peaks in discovery rate can be inferred with some confidence. The build-up probably began with the appointment of Lieut.-Governor Arthur, during whose term of office exploratory work by Hobbs and others, visits by Scott and the report of 1826 of the Land Commissioners resulted in marked increase in knowledge of mineral distribution, including coal. The next step was the appointment of George Frankland as Surveyor General, commissioned by Hay on behalf of Earl Bathurst to collect "information in regard to Geology and Natural History" (HRA III(5): 234). Surveyors Woodward and Hughes, under instructions from Frankland to survey Tasman Peninsula, found coal at Saltwater River early in 1833. The subsequent mining of this coal alerted the public to the importance of this mineral. Sir John Franklin, the Lieut.-Governor who followed Arthur, fostered knowledge of science, including geology, and entertained and encouraged visiting naturalists like Strzelecki, Jukes, Sir John Ross and others. Strzelecki is perhaps noteworthy in this respect as he visited many parts of Van Diemens Land, examined coal seams and analysed some of the coal. These activities probably drew the attention of people in many parts of the State to the occurrence of coal. The possibility of using coal mining as a useful occupation for convicts was certainly favourably entertained by Lieut.-Governor Sorell and then by Arthur and later Lieut.-Governors, and several abortive attempts were made to develop this possibility (e.g. Jerusalem and Schouten Island). The possibility of commercial exploitation of coal also emerged publicly in 1840 with an attempt to mine coal at Southport (see later) and was followed by others. The discovery of copper ore in South Australia led to the need for coal (or coke) for smelting, and a company was formed in Tasmania in 1848 to supply this need.

Impetus was added to the already accelerating rate of discovery when Lieut.-Governor Sir William Denison was asked by the Lords of the Admiralty in 1847 to obtain a report on coal in Tasmania so that coal supplies for bunkering the increasing number of steam-driven vessels in the British Navy could be ensured (TSA Outward Despatches 67; 18 May 1849). He commissioned Joseph Milligan on 14 January 1848 to examine the coalfields (TSA 24/261/5844, CSO 24/40/1257), and detailed the sort of information he required on 31 January of that year. Denison asked Milligan to concentrate on coal basins near the coast, to report on quality, locality, especially with respect to ease and distance of transport, and the presence of faults and "dikes", on the topography as it influenced mining, on the thickness, dip and associated rocks and on the means of removing water from any mine.

The first report, that on Schouten Island, was completed by 15 August of that year (*Proc. R. Soc. VDL* 1: 1). The second report was commissioned on 28 August 1848 (Milligan 1849: 31); this was to be on Fingal and Mt Nicholas (completed 8 November 1848) and on Richmond and Jerusalem (now Colebrook) (completed on 13 February 1849, *Pap. Proc. R. Soc. VDL* 1: 67). After coal was discovered in the Mersey area, Milligan was commissioned to report on that field (31 March 1851: TSA 24/261/5844).

The discovery of coal on the Don River early in 1851 was followed by intense exploration activity there involving a number of individuals and groups. Many discoveries followed in the area within the decade. During his exploratory activity Lieut.-Governor Fox Young commissioned A.R.C. Selwyn of the Geological Survey of Victoria to report on the coalfields. His activities, and controversy arising therefrom, were reported in the Tasmanian press, thus indicating and probably increasing public interest. The growth in the discovery rate leading to this first peak suggests a multiplier effect, in that one or a few events produced interest which led to more discoveries which triggered further interest...

Why did the rate not continue to rise after 1860? For one thing, the population increase slowed; for another, Tasmania entered a period of economic stagnation (McGhee 1969: 138). Mersey coal was not proving as profitable as expected. Mines had already opened and closed in the 1850's, due to thin seams and the frequency of faults. The Select Committee on coal which reported in 1864 had heard evidence that the coal was suitable only for steam-raising, and competition from the better coal sold by the much more developed NSW coal industry ensured that production of Tasmanian coal was mainly, if not solely, for use within the State, i.e. it had a relatively small market.

The population began to rise again in the decade beginning 1881 and railways had been opened (Launceston to Deloraine 1871, Hobart to Launceston 1876). During this decade (1886) the

line from Conara Junction to St Marys was opened. The railways not only provided a steady new market for the coal but also access to the coalfields. The discovery of tin at Mt Bischoff in 1871 brought population to new areas, increasing the chance of discovery of metals and coal. From Bischoff, in fact or in effect, waves of prospectors spread into previously remote or inaccessible parts of western Tasmania and the Central Highlands and discovered metalliferous deposits. Prospectors and timber cutters working out from the new metalliferous mineral discoveries also discovered coal. The later part of the last century was also the time of development in the Huon district (Scott 1965: map 8, Centenary of Settlement of the Huon. Huon Newsletter Newspaper Co., Franklin 1936) — orcharding in the valleys near the Huon River and timber-seeking and then logging in the higher country and further away. The timber-seeking and logging activities provided access to new areas and coal discoveries followed. The second peak in discovery rate thus seems to have been influenced by population rise, opening of railways, discovery of metalliferous mineral deposits and the development of the timber industry. To some extent the second peak also reflects the activities of one man, Robert Mackenzie Johnston, in collating information on coal and publishing some discoveries, mainly of lignite, for the first time (Johnston 1873, 1888).

The discovery rate fell off again in the first two decades of the 20th century. Another depression had started in the 1880's and deepened in the 1890's (L'Huillier 1969: 186), and its effects lasted into the first years of this century. Subsequently the First World War diverted attention and manpower away from relatively minor activities like coal search. Late in the War and in immediately post-war years, governmental interest in possible sources of power for industry led to systematic geological survey (Hills *et al.* 1922: 268–269); this resulted in the recording of some discoveries but, in addition, probably triggered interest from prospectors or entrepreneurial groups, from which a few discoveries also flowed. After 1930, the rate of discovery fell drastically as the economic depression of the late twenties and thirties took hold and it was not until the post-World War II decade of the 1950's that higher population growth, some of it by immigration, and booming economic conditions again provided support and incentive for coal search from which some discoveries followed.

The great activity in coal search in the 1970's, triggered by marked increase in the price of oil, was mainly directed to further exploration or development of known fields rather than search for new ones. Nevertheless a new field, at Woodbury, was discovered and another, previously neglected, at Rosevale was "rediscovered". Subsequent finds seem to be minor and have occurred during geological work by the Department of Mines.

It is interesting to note that discovery of black coal has always excited much more interest than that of lignite in Tasmania. The difference in interest is probably a function of the greater value of black coal and the greater thickness of seams in the black coal.

INCREASING KNOWLEDGE OF THE GEOLOGY OF TASMANIAN COAL

As a background to the history of geological study of coal to be outlined in this section, a summary of present knowledge may be useful. The oldest Tasmanian coals are Early Permian in age and lie between sequences of marine rocks. Above the higher of these marine sequences are Upper Permian coal measures, separated in turn by a fluviatile succession from the main coal measures of Late Triassic age. The Permian and Triassic coals are black and occur as almost horizontal to gently dipping beds commonly disrupted by faulting or by intrusions of Jurassic dolerite, in the form of sills, sheets or dykes.

Because of the disruption, individual coal-bearing blocks may be only a few hundred metres in maximum horizontal dimension. Prediction of seams across faults and through dolerite intrusions is extremely difficult. Brown coals and lignites of Early to Mid-Tertiary age occur as horizontal beds in a number of places.

The early discoverers of coal in Van Diemens Land were careful to note the thickness and number of seams, the economic aspects. Thus even the earliest record of coal in Tasmania, that of Labillardière (1800), included comments on the thickness of the seam and on the associated sedimentary rocks, and noted that they were horizontal. McCarty (*Hobart Town Gazette* 15 June 1816) and Kelly (HRA III(3): 466) commented on the thickness and number of seams at Macquarie Harbour. In J.T. Bigge's Commission of Enquiry (HRA III(3): 257) it was noted that the seam at Adventure Bay was two feet (0.6 m) thick and dipped a little to the southwest.

Archdeacon Thomas Scott (1824) regarded rocks at Hobart and George Town as being of the "the coal formation", i.e. like the Permo-Triassic rocks near Sydney and Newcastle which he referred to as

"the coal measures", inferring thereby a Carboniferous age for them by lithological correlation with Great Britain. Winch (1823) noted the presence of fossil leaves above and below the coal at "Hobart's Town" and also assigned a Carboniferous age to the coal.

Early in 1824 John Busby (or Bushby) reported on coal and water near Hobart (*Hobart Town Gazette* 20 February 1824). He noted three seams at Richmond and gave strike and dip (30° to the SSE). The lowest seam (1.2 m thick), he noted, lay between sandstone beds and contained thin strata of clay. He noticed the proximity of "whin" (dolerite) dykes to which he attributed the dip of the seam and the low "combustibility" of the coal. He also recorded that the coal was brittle. A coal specimen from Schouten Island he likened to splint coal, which, because of its "tenacity", he thought was likely to carry well. He disputed the correctness of a report (untraced) by one Jackson on the Macquarie Harbour coal. In a report to Lieut.-Governor Arthur (CSO 1/67/1351) Hobbs raised the possibility of a vein of coal running (with dislocations) from Hobart to South Cape Bay.

The report by Winch (1823) on coal at New Town probably had little effect in Hobart Town as it was published in a British scientific journal. More local attention was attracted by reports in the *Hobart Town Gazette* (12 May 1827) of coal dug up in a well on Mr Emmett's farm on New Town Road, and there was a further report in 1829.

In travelling through Lenah Valley to the upper reaches of Tolosa Street, Glenorchy, in February 1836, Charles Darwin saw coal, again in close association with dolerite (Banks 1971).

Sir John Franklin commissioned a visiting Polish explorer, Dr John Lhotsky, late in 1836 to report on the coal and coal mining at Saltwater River. Lhotsky was to be paid ten shillings a day. His arrival on 17 February 1837 was noted by the Commandant, O'Hara Booth (Heard 1981: 207). His report (CSO 5/72/1584) included a geological section of a shaft 24 m deep in sandstone and shale with plant impressions. He provided both a neat, detailed map of the coal-mining area itself, showing the coal trending west-northwest between sandstone beds, and a map of the Forestier and Tasman Peninsulas showing, in colour, small areas of "trap" (= dolerite), greywacke (Permian Fern Tree Mudstone), sandstone (Triassic), and coal measures (also Triassic), some of them in contact. This is the earliest attempt at a geological map of any part of the State. He made some very sensible suggestions for working the mine, including keeping records of strata cut in boring or shaft sinking. Lhotsky used a theory of coal formation current at the time — chemical softening of igneous matter followed by heating under various pressures (Macculloch 1831). He used a theory that much coal was deposited at the foot of and along the flanks of "primitive" mountains (i.e. mountains of igneous or metamorphic rocks) to suggest deeper drilling and seeking better coal elsewhere.

Faulting was recognised — as "throws" in the Saltwater River mine as early as 1834 (O'Hara Booth's journal, Heard 1981: 179). A report to the Executive Council dated 1 September 1841 (LSD 1/28/458–464) provided not only a description of the stratigraphic succession involving the coal at Jerusalem but also a geological sketch section from Jerusalem to Richmond, showing southerly dipping beds dislocated by normal faults downthrowing to the north. No author is quoted for this report but it could well have been the Polish explorer, Strzelecki, who was in Tasmania at the time (compare this report with Strzelecki 1845: 127). P.E. von Strzelecki recognised two coal "basins" in Tasmania, the South Esk Basin in the Avoca to St Marys area and the Jerusalem Basin in southeastern Tasmania. The coals in these basins he placed in the "Third Epoch", as he did also those in the Newcastle Basin of NSW (1845: 123) but commented cryptically (but correctly as it proved) that the "deposits... seem to differ in point of date". As it is, he included the Late Permian Southport coal with the Late Triassic coal from other areas. He even suggested (*ibid.*: 129) the possibility that the Jerusalem coals might be older than those from the South Esk (same age) and Newcastle Basins (actually older than Jerusalem coals). He described and provided both proximate and ultimate analyses of coals (see also Strzelecki 1842), as well as analyses of gases derived by burning of coal from Port Arthur (Saltwater River), Richmond, Recherche Bay, Colebrook and Jericho, and of lignitic wood and earthy lignite (from Nine Mile Marsh). He generally named the coals using the system of Jameson (1808), with names according to Brongniart (1807) as subtitles. His ultimate analyses must be suspect as he recorded nitrogen contents usually about 10% but up to 16%. Later analyses for nitrogen (Hills *et al.* 1922: 28–30) are of the order of 1%. The method of analysis of nitrogen is not stated. The H_2S content of the gas resulting from burning the coal also seems too high, up to 18%. On the positive side, it should be noted that Strzelecki was the first to publish a statement on the faulting of the coal, observed the coking effect of dolerite intrusions at Recherche Bay and Southport (*ibid.*: 141) and first correlated

coal seams (one at Jericho with the upper seam at Jerusalem (*ibid.*: 139)).

While in Australia, Strzelecki collected fossil plants which he gave to J. Morris in England for description. Under the heading "Carboniferous Flora" (Strzelecki 1845: 245) Morris described (a) *Glossopteris browniana* from Newcastle, likening it to *G. phillipsii* (now *Sagenopteris*) from the Oolitic (Jurassic) of England; (b) *Pecopteris* (now *Cladophlebis*) *australis* from the Jerusalem Basin, likening it to two species from the Oolitic Series and noting its analogy to *P. lindleyana* of the Burdwan Coalfield of India, then regarded as Oolitic in age; (c) *P.* (now *Dicroidium*) *odontopteroides*, likened to a Permian fern *Odontopteris permiana* from Russia, which he recorded from the Jerusalem Basin; and (d) *Zeugophyllites* (now *Phoenicopsis*) *elongatus* from the Jerusalem Basin. Morris remarked (*ibid.*: 251) that neither in the Hunter nor in the Jerusalem Basin did any of the characteristic plants of the Carboniferous coal measures of Europe occur, and seems to have been uncertain of the contemporaneity of the Hunter and Jerusalem basins ("if indeed contemporaneous": 252). He attributed the differences in fossil content to geographical variation. He then went on (*ibid.*: 253) to note the similarities of the Hunter and Jerusalem Basin floras taken together with that of the Burdwan Coalfield of India and the Oolitic of England. In making such comparisons he was deceived, as was M'Coy a little later (1847), by homeomorphy (similarity in form) of leaf form and venation in the fossil plants. M'Coy (1847, 1848) compounded the confusion by insisting that the coal measures at Newcastle in the Hunter Basin were the same age as the coals of the Jerusalem Basin because of the presence in both of *Pecopteris odontopteroides* and *Zeugophyllites* (a misidentification in the Newcastle sequence of *Noeggerathiopsis* = *Cordaites*). He also insisted that both were Jurassic (Oolitic) by correlation with Burdwan (actually Permian) and the Oolitic of northern England. Thus began the notorious controversy between M'Coy and W.B. Clarke on the age of the Australian coal measures (see Vallance 1981 and Murray 1983), Clarke maintaining a Carboniferous age.

A major advance in knowledge of coal came with the commissioning of Joseph Milligan by Sir William Denison to report on Tasmanian coals. Joseph Milligan had come to Tasmania in 1831 with a diploma in medicine from the University of Edinburgh to be a surgeon with the VDL Co. (Hoddinott 1967: 230–231). Attention has already been drawn to his record of coal from near Hampshire in 1832 and his commissions from Denison to report on the coal basins. By 1852 his reports on coal at Schouten Island, South Cape, Whale Head, Fingal, Mt Nicholas, Richmond, Jerusalem and the Mersey had been published. He described the coal-bearing beds and especially the coal, very clearly and provided accurately measured stratigraphic sections as well as accurate, realistic cross-sections, the first in Tasmania. He correctly inferred the sill-like nature of the dolerite body on Mt Nicholas and that the dolerite on Ben Lomond was younger than the coal (*Pap. Proc. R. Soc. VDL* II(I): 166), contrary to the views of Strzelecki. In Milligan's view the coals at all the places noted were the same age and Carboniferous. Milligan recognised three types of coal — cannel, bituminous and anthracite. For each coalfield studied, Milligan commented on the quality and quantity of coal available and in several places estimated reserves. He noted the distribution and structure of the coal areas, described or recommended mining methods and made a careful study of the access for coal to means of transport and the Tasmanian market, thus satisfying the terms of Denison's commission. He recommended the development of some fields, further exploration of others and neglect of the South Cape-Whales Head field. He was not enthusiastic about the prospects of coal on the Don River.

Probably arising from this survey Denison sent specimens to de la Beche, Director of the Geological Survey of Great Britain, for analysis. De la Beche (1851) was not impressed, largely because of the ash content but partly also because of the sulphur content — "the coals cannot be considered as at all first class coals".

Less than ten years later, Governor Sir Henry Fox Young commissioned the Chief Geologist of the Geological Survey of Victoria, A.R.C. Selwyn, to report on the coalfields. Selwyn visited Tasmania in April and May 1855 (Dunn 1910: 9) and reported, adding comments on new fields near Plenty and near Triabunna as well as bringing up to date information on the rapidly developing Mersey field. Selwyn was misled by the apparent lack of metamorphism of contiguous sedimentary rocks by the dolerite into considering that some of the dolerite was older than the "carboniferous" sediments, e.g. in the Douglas River area (1855: 126). As a result he postulated incorrectly that coal would not pass beneath the dolerite near the present Duncan Mine, southeast of Fingal. He was also misled by the known sections in the South Esk Valley, in the Sydney Basin and in Britain, where coal overlies fossiliferous marine beds including

limestones, to suggest that, in the Mersey Basin, once marine fossils were encountered in drilling, further drilling would not reveal coal. He was right for the particular shaft he was discussing but wrong to try to apply the principle generally in the Mersey field, as pointed out by Zephaniah Williams, a local mine manager (see Burns 1964: 89, 95, 222 *et seq.* for details). He assumed that known coals in Tasmania were all of one age.

The advent of the first Geological Surveyor of Tasmania, Charles Gould, in 1859 brought for the first time a trained geologist into a full-time professional position in Tasmania. Gould, a son of the famous ornithologist John Gould, graduated from the University of London, where his teachers had included the well-known field geologist Andrew Ramsay and the famous biologist and palaeontologist Thomas Huxley. He had subsequently worked in the Geological Survey of Great Britain under Sir Roderick Murchison. As early as August 1859, he was working on coal at Fingal, and over the next ten years he visited and reported on most of the coalfields including the Mersey field. By mid 1861, Gould had recognised that the coal in the Mersey field was not the same age as that in the Fingal Valley (letter to Murchison) and he published that view later in the year (Gould 1861b), thus breaking one of the links in M'Coy's argument that the Newcastle and Jerusalem coals were equivalent and Oolitic in age, and anticipating by eleven years Daintree's (1872) conclusion that both Palaeozoic and Mesozoic coals were present in eastern Australia (Murray 1983: 8). In that same report Gould also showed that coal occurs below rocks with Upper Palaeozoic marine fossils, thus proving Selwyn wrong. Further, in another report in 1861 (*HAJ* pap. 9) on the Mt Nicholas Field he provided good stratigraphic sections of the succession on St Pauls Dome and in Piccaninny Creek, and showed in a geological cross-section the coal passing beneath the younger dolerite cap on Mt Nicholas. In that same year, 1861, he also suggested (*HAJ* pap. 65) the establishment of a Coal Commission, which was subsequently set up with Gould as one of its members. A few years later (1865: 63–66) he summarised his views on two ages of coal in Tasmania and on the age of the dolerite.

By 1888, the general sequence of the coal-bearing beds in the Sydney Basin, i.e. Lower Marine Beds, Lower Coal Measures, Upper Marine Beds, Upper Coal Measures, had been recognised (Clarke 1878:66) and some of the plant fossils characteristic of each of the two coal measures were known. In addenda to *A Systematic Account of the Geology of Tasmania*, R.M. Johnston (1888: 202–207) arrived at essentially the present understanding of the situation with respect to the number and positions of coal measures in Tasmania. He noted the occurrence, beneath Upper Palaeozoic marine beds in the Harefield Bore, of coal measures equivalent to the Mersey, equated the coal at Cygnet with that at Adventure Bay on stratigraphic and palaeobotanical grounds and went further to correlate the Adventure Bay and Cygnet coals with the Newcastle (Upper) Coal Measures of New South Wales. The main coal measures of southern and eastern Tasmania he placed as Mesozoic, rather than assigning them to a particular period, being unable to discover in them fossils diagnostic of any one of the Mesozoic periods in Europe (1888: 160). He had earlier published descriptions of some of the plants from the Triassic coal measures (Johnston 1887). Johnston (1888: 100–103, 166) followed Jukes and Selwyn in regarding the bulk of the dolerite as pre-Carboniferous and expressed this view in sections (e.g. opposite p.163). For example, he showed the coal measures abutting against dolerite southeast of Fingal (contra J. Milligan). A few years later, Johnston (1894: 172) removed the coal at Southport from the Mesozoic on the basis of fossil plants there and equated it (correctly) to the Adventure Bay and Cygnet Coal Measures. Johnston was a Scot who may well, as a boy, have been familiar with the work of Hugh Miller of Old Red Sandstone fame as he came from the same part of Scotland. Before coming to Australia he probably studied some geology at Glasgow University but he had no degree. His first position in Tasmania was as a clerk in the Launceston and Western Railway Co. While in Launceston he studied and wrote papers on the Tertiary sedimentary rocks and fossils of northern Tasmania. After moving to Hobart, where he became Government Statistician and Registrar-General, he studied the Tertiary but later, and more importantly, the Permian and Triassic rocks of southeastern Tasmania. He was commissioned by the Government of the day to write a book on the geology of Tasmania. The result was the classic *A Systematic Account of the Geology of Tasmania* published in 1888. He continued to work on aspects of the geology of the State among many other activities for a couple of decades. His main contribution was the *Systematic Account* ... and his views on the coal-bearing sequences influenced work on these sequences for almost seventy years.

Twelvetrees (1902a: 67) regarded the Mesozoic coals as Jurassic except for that at Ida Bay (Triassic).

The need to understand the coal resources of the State at a time of industrial development and hydro-electric power development led to the systematic survey and reporting of the coals and coalfields published as *Geological Survey of Tasmanian Mineral Resources No. 7* by the Department of Mines (Hills *et al.* 1922). The stratigraphic framework used was essentially that of Johnston (1888), i.e. Lower Coal Measures and Upper Coal Measures of Permo-Carboniferous age and the Trias-Jura coals together with minor Tertiary lignites. Within the Trias-Jura eight coal seams, specified by Greek letters from Alpha to Kappa, were widely recognised and correlated, suggesting or assuming original continuity from one locality or another. This simple scheme cannot be maintained. Hills *et al.* (1922: 8–9) recognised the variability in form of the dolerite intrusions and noted that intrusion was accompanied by faulting. The importance of major and minor faulting in controlling the location of the coalfields and the mining practices in particular collieries was also recognised (*ibid.*: 10–11). The nomenclature of the coals used, i.e. anthracite, sub-anthracite, humites (including non-caking humic, caking humic and gas-making humic), humic kerogenites, kerogenites, sub-humites and lignites (or brown coals) was adopted on the basis of convenience (Hills *et al.* 1922: 13). In their discussion of the ash content Hills *et al.* (*ibid.*:16–17) wrote of periodic flooding and wind transport; this seems to be the sole comment even hinting at the conditions of deposition of the coals. The treatment in this work was essentially economic and local, as was appropriate to its aim, but little opportunity was taken for comparative studies, e.g. between seams within the same succession, between Early Permian and Late Permian and Late Triassic coals, and between coals of the same age in different places. Proximate analyses were carried out on carefully produced samples of each seam. However, ultimate analyses, heat value analyses, were made and specific gravity determinations carried out on groups of samples from a district. The ultimate analyses were on dry whole rock, not dry ash free (daf) or dry mineral matter free (dmmf) basis, so direct comparison between coals is not easy. For each coal-bearing area the geology and topography as related to mining were noted, the stratigraphy within seams detailed and the tonnage of the reserves quoted. Some attention was paid to the history of discovery and exploitation in the various fields and in the State as a whole, but the history provided was both incomplete and, in places, inaccurate. Plants collected by members of the Geological Survey during work on the Triassic coals were subsequently described by A.B. Walkom (1925, 1926), Director of the Australian Museum, Sydney, who correlated the coal measures with those of Ipswich, Queensland, and assigned a Rhaetian age to them. The coals were then assigned a Triassic age as reflected in Nye & Blake (1938: 47–49). In a passing comment these authors referred to the lacustrine or swampy conditions of deposition of the Triassic coal measures, reflecting a comment by Johnston (1888: 162). In 1938, Arndell N. Lewis, a prominent local amateur geologist, and A.H. Voisey, a visiting professional geologist, recognised a volcanic component in the sandstones associated with the Triassic coals (Lewis & Voisey 1938).

Dr John and Mrs Roma Dulhunty, from the University of Sydney, published the first palynological studies of Tasmanian coals (Dulhunty & Dulhunty 1949) and showed approximate correlations of the Mersey and Cygnet Coal Measures with the Greta and Newcastle Coal Measures respectively but seem to have erred in regarding the Preolenna Coals as equivalent to the Upper Coal Measures. Subsequently Dr Mary Dettman (1961), then at the University of Cambridge, suggested a Rhaetian age for the Triassic coals on the basis of palynology. Later palynological studies of the Permian coals by Dr Elizabeth Truswell of the Bureau of Mineral Resources (in Truswell 1978 and Calver *et al.* 1984) have refined the correlations of the Mersey and equivalent coal measures and demonstrated that they are older than the Greta of New South Wales. Dr Geoff Playford from the University of Queensland (1965) showed that the Brady Formation and several other Triassic coals are Late Triassic, probably Rhaetian in age. Banks (1978) assigned a possible range from Anisian to Norian to the coal measures. Recently Forsyth (1984: 83), the first Tasmanian palynologist to study the coal sequences, has extended palynological work on the Triassic considerably and shown that the Triassic coal measures are Karnian in age.

The palaeogeography of the Permian coal measures received some attention from Banks (1962: 204–205, 211) who postulated deposition on extensive coastal flood plains with peat swamps. In the same volume G. Hale, Hydro-Electric Commission (1962: 224), suggested deposition of Triassic coals in a number of small lakes and Dr J.A. Townrow (1962: 230), a palaeobotanist at the University of Tasmania, suggested, by inference, peat swamps supporting large trees. Townrow later (1964) suggested the possibility that the

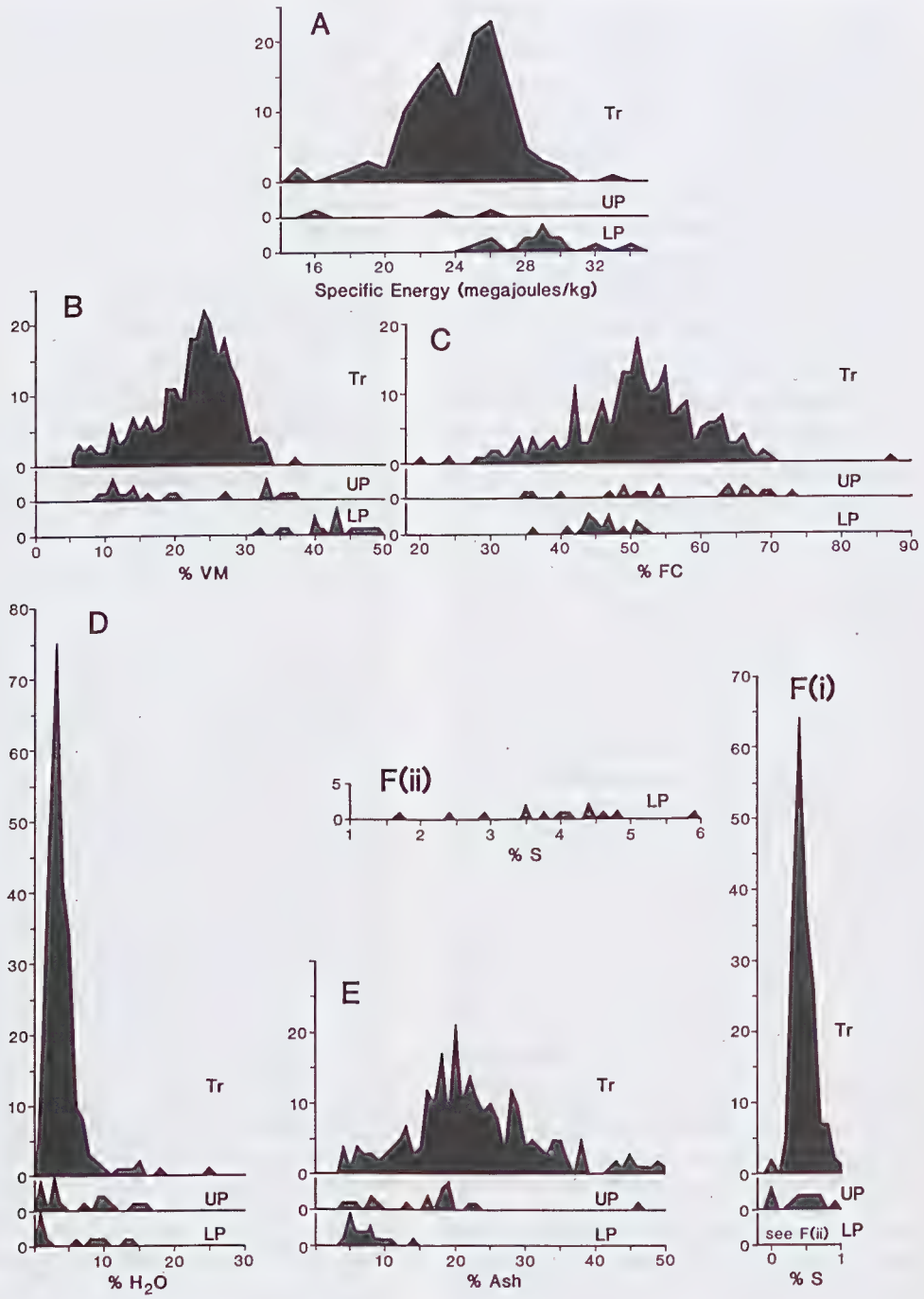

A
Tr
UP
LP
Specific Energy (megajoules/kg)
B
% VM
C
% FC
D
% H_2O
F(ii)
% S
E
% Ash
F(i)
see F(ii)
% S

TABLE 1

Summary of Properties of Tasmanian Black Coals with comparative figures for NSW Coals

Property	Age	Range		Modal value
		Min.	Max.	
Moisture %	Triassic	0.6	25.4	3
	Upper Permian	0.8	15.83	3
	Lower Permian	0.5	13.58	1
	Newcastle, NSW	2.2	3.3	
Ash %	Triassic	3.7	50.00	20
	Upper Permian	8.67	46.5	19
	Lower Permian	4.00	13.72	5
	Newcastle	7.6	15.5	
	South Coast, NSW	10.6	21.6	
Sulphur %	Triassic	0.03	0.96	0.4
	Upper Permian	0.00	0.9	0.5
	Lower Permian	1.7	10.5	-
	Newcastle	0.3	0.5	
	South Coast	0.28	0.57	
Volatile matter (VM) %	Triassic	6.8	37.5	24
	Upper Permian	9	36.9	11
	Lower Permian	32.4	48.9	43
Fixed Carbon (FC) %	Triassic	19.52	87.34	51
	Upper Permian	35.49	72.58	-
	Lower Permian	36.0	52.3	-
Specific energy (SE) (mj/kg)	Triassic	15.48	33.1	26
	Upper Permian	16.2	26.34	-
	Lower Permian	24.91	33.8	-
	Newcastle	33.05	34.82	
	South Coast	34.84	36.05	

Moisture measured on air-dried samples (see Hills *et al.* 1922: 23). Ash determined in the residue of dried coal from the moisture determination. Sulphur measured in air-dried coal by the Eschka method. Volatile matter measured by heating 60-mesh air-dried coal, determining loss in weight and subtracting moisture content from the loss in weight.
Fixed carbon value is the difference between 100 and the sum of the moisture, ash and volatile matter. Specific energy measured using 80-mesh coal.
Analyses of Triassic coals (close to 240) reveal that (a) 56.5% have moisture content of 3% or less; (b) 50% have an ash content greater than 21.5%; (c) 58% have sulphur content of 0.4% or less; (d) the mid-point of the distribution of VM is 23%; (e) the mid-point of the distribution of FC is 51%; (f) the mid-point of the distribution of SE is 25 mj/kg.

Sources: Tasmanian figures based on analyses plotted in figure 3 plus two analyses from Reid (1919); NSW figures (for washed coals) from Crapp & Nolan (1975: 166), Wilson (1975: 212).

FIG. 3 (opposite) — Histograms of properties of Tasmanian black coals; properties along horizontal axes, number of samples along vertical axes; actual analyses (except percentage sulphur) rounded off to closest integer — thus numbers in range 19.51 to 20.5 rounded off to 20; in the case of sulphur in Upper Permian and Triassic analyses rounded off to nearest decimal point — thus 0.16 to 0.25 rounded off to 0.2. (A) specific energy in megajoules/kilogram; (B) percentage of volatile matter (from proximate analysis of air-dried coal); (C) percentage of fixed carbon (from proximate analysis of air dried coal; (D) percentage of water (from proximate analysis of air dried coal); (E) percentage of ash (from proximate analysis of air dried coal); (F) percentage of sulphur, (i) mainly Upper Permian and Triassic, (ii) Lower Permian. Analyses from Hills et al. *1922 (table 1), unpublished reports of Department of Mines, Tasmania, by C.A. Bacon 1983–86 and from a report by the Hydro-Electric Commission on coal at Fingal, incomplete analyses and those with ash >50.1% not included.*

climate under which the Late Triassic coal measures were deposited was cool temperate.

Although Milligan (1851) recognised that there were different types of sandstone associated with the coal now considered Triassic, he did not establish the correct stratigraphic relationships. This was done by Selwyn (1855: pl. 1, fig. 1) who noted a yellow sandstone below the coal and a greyish-brown sandstone associated with the coal. A geologist with the very newly formed Geological Survey, A. Montgomery (1891:15–16) recognised that the yellow sandstone was "very quartzose", the greyish-brown one "composed chiefly of fragments of a felspathic rock", and referred to the latter as "felspathic sandstone", a name which, although incorrect, has been replaced only in the last 25 years.

Only recently has sedimentological study of the Triassic coal measures been attempted. These studies suggest deposition within a fluvial system of meandering streams under temperate conditions of pronounced seasonality (Morrison & Bacon 1986). The presence of contemporary vulcanism, suggested by Lewis & Voisey (1938), has been confirmed by the discovery of rhyolitic ash fall tuffs (Bacon & Everard 1981). Petrological work on the Triassic coal itself was first done by Ms M. Smyth, CSIRO Division of Fuel Research (1979), who inferred from the the relative richness of the inertinite macerals that processes of decay were largely aerobic with flooding of bog surfaces with oxygenated waters. Later the Duncan Seam was assigned a palsamire origin with islands of trees growing in a swamp consisting predominantly of muskeg type vegetation, all under continuous permafrost (Smyth 1980). This very cold environment was not accepted by Morrison & Bacon (1986), who postulated a vegetation of xerophytic woodlands growing on levee banks and higher parts of the flood plains, with broad-leaf forests of ferns, seed ferns, ginkgoalean and cycadalean trees in abandoned channels and the lower parts of the floodplains, and scouring rushes flourishing in the wetter areas. This general environment was suggested by Bacon (1986b) for Late Triassic coals at Mt Nicholas, Fingal, Merrywood and Avoca in northeastern Tasmania.

Maceral analysis of the Early Permian coals from the St Marys area by Bacon & Calver (1986) and of the Preolenna coal by Bacon (1986b) led to suggestions of a back barrier depositional environment contrasting with the dry forest swamp environment common in the Late Triassic.

Very few vitrinite reflectance values of Triassic coals have been published, that on the Duncan Seam (Late Triassic of Fingal) being the first (Smyth 1980: 177).

Although lignites have been known to occur in Tasmania since 1815 and have been reported from time to time in several places (see appendix 1) none have yet proved sufficiently economically attractive to mine on a long-term basis. Johnston (1888: 269–294) referred the lignites he mentioned to the Upper Palaeogene. The first good evidence on the age of the lignites was palynological (Cookson & Duigan 1951) and later palynology by Cookson (1953, 1954, 1956, 1957, 1967 and in Gill & Banks 1956) and Harris (1968) has allowed the recognition of Palaeocene, Eocene and Mid-Tertiary lignites.

The highlights of the work on the geology of Tasmanian coals have been (a) Lhotsky's report with his postulation of environment of deposition in 1837; (b) the careful stratigraphic work by Joseph Milligan; (c) the structural work and recognition by Charles Gould of the presence in Tasmania of at least two coal horizons; (d) the establishment by Robert M. Johnston that there were three coal horizons; (e) the systematic survey of the coal resources by Hills and his colleagues; (f) recent work on palynology by Dettman, Playford, Truswell and Forsyth; (g) the inception of sedimentological work by Bacon and others; and (h) the application of maceral analysis by Smyth and then Bacon.

Most of the early work was done by visitors, often short term, and in many cases with little training in geology. Charles Gould was the first trained geologist to spend more than a few months in Tasmania and work on the coals. Loftus Hills was a Tasmanian with a degree in geology and one of his collaborators, A. McIntosh Reid, had received training in Tasmania under W.H. Twelvetrees. Other collaborators with Hills, P.B. Nye and H.G.W. Keid, had degrees in geology from Melbourne and Brisbane respectively but spent a long time in Tasmania. In recent years, work on coal in Tasmania has been dominated by trained geologists, born in or with long association with Tasmania e.g. C.A. Bacon, C.R. Calver, S.M. Forsyth and K.C. Morrison.

Except perhaps for the work by Gould on the stratigraphy of Tasmanian coals in the 1860's, work on these coals has been mainly of local significance. It has, in the main, been the application of ideas and techniques developed elsewhere, commonly years to decades before, to the Tasmanian scene. The derived and delayed nature of the work is hardly surprising in view of the local nature and relatively small scale of the Tasmanian

coal industry. There is, however, scope for fundamental work in study of the petrology, sedimentology and palaeoecology of coals formed under cool to cold temperate, high latitude conditions.

QUALITY OF THE COAL

As early as 1824 comment was made on the poor quality of the coal at Richmond (Busby, *Hobart Town Gazette* 20 February 1824). Soon after coal from Saltwater River started being used for office heating in Hobart Town there were implicit complaints about its low quality (LSD 1/79:24). Strzelecki (1842,1845) published the first quantitative analyses but, as noted earlier, some of his figures are suspect. De la Beche (1851) was not impressed with the coal because of its high ash content, as shown in his analyses, and the Select Committee on Coal (Horne 1864) reported that there was no coal worth exploiting as a State undertaking. A few analyses were published by Johnston (1888) and others were made from time to time of coal samples collected by officers of the Geological Survey of Tasmania. Hills *et al.* (1922: 28–30, table 1) brought together many earlier and original analyses; these showed the Lower Permian coals to be low in ash, intermediate in moisture and high in sulphur, with higher volatile matter (VM) and somewhat higher specific energy (SE) than the Triassic coals (fig. 3). Upper Permian coals had higher ash than those from the Lower Permian, about the same moisture content, mostly medium sulphur with some low and rare high sulphur coals, and lower VM and SE. These analyses made clear the high ash content and relatively low SE of the Triassic coals, which, however, had low moisture and sulphur contents. About 60% of Triassic coals were medium-sulphur coals in the sense of Hunt (1987: 14), 40% low sulphur with some rare high sulphur coals. Figure 3 and table 1 show graphically and in summary the properties of Tasmanian black coals; they are based on the analyses in Hills *et al.* (1922) and in a series of unpublished reports of the Department of Mines prepared by C.A. Bacon over the last decade. There are probably still not enough analyses of Permian coals to allow of definitive statements but it seems unlikely that additional analyses will change the known distribution of the properties of the Triassic coals significantly.

A preliminary analysis of seam thickness suggests that in the Permian coals seams are thin, commonly less than a metre, and there are no seams more than 1.2 m thick. The great majority of seams in the Triassic are also a metre or less in thickness, but there are some more than 1.5 m thick (Morrison & Bacon 1986, fig. 1) and a few, especially at the southeastern and northeastern edges of the present extent of the coal basin, which are more than 3 m thick, e.g. Catamaran — up to 10 m but with ash 30–40%; Fenhope — 3.6 m; Merrywood — up to 5.2 m; Dalmayne — up to 7.35 m (largely carbonaceous mudstone); Fingal Tier — Seam B commonly 10 m thick (interbedded coal and mudstone), Seam C 16.89 m thick (also interbedded coal and mudstone) (Unpubl. Reps Dep. Mines Tasm.1983/08, 1983/22, 1983/07, 1984/10, 1983/46).

Recalculation of analyses in Hills *et al.* (1922, table 1) and in unpublished reports by Bacon and others (Unpubl. Reps Dep. Mines Tasm. 1983 to 1986), on a dmmf basis using the Parr formula (as in Ward 1984: 62), showed a fixed carbon percentage ranging from 43.27 to 96.28. The results are summarised as table 2 and figure 4. Lower Permian coals are predominantly high volatile bituminous coals (esp. High Volatile A), Upper Permian coals medium volatile to semi-anthracite, and Triassic coals sub-bituminous A to anthracite especially medium volatile bituminous, using the ASTM limits for ranks (Ward 1984: 69). International and Australian standard classification of hard coals were not applicable because for the large majority of coals analyses did not contain sufficient

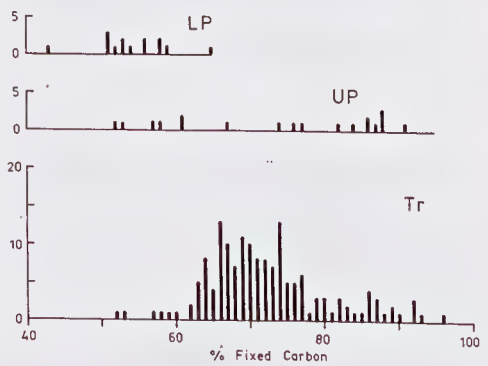


FIG. 4 — Histograms of fixed carbon content of Tasmania coals. Percentage calculated according to method described in explanation to table 2 from proximate analyses in Hills et al. *(1922) and in unpublished reports by Bacon and others (1983 to 1986).*

TABLE 2

ASTM Rank* of Tasmanian Coals

		Lower Permian	Upper Permian	Triassic
Anthracite				
Anthracite				4
Semi-anthracite			5	10
Bituminous				
Low volatile			4	17
Medium volatile			3	67
High volatile	A	6		17
	B	4		15
	C	2		5
Sub-bituminous	A			2
Rank uncertain†		2 (FC 51,56)	7 (FC 52–67)	22 (FC 52–68.68)
		14	19	159

Highest FC
Triassic – Catamaran (96.28%)
Upper Permian – Cygnet (91.26%)
Lower Permian – Preolenna (65.02%)

FC below 60%
Triassic – Bagdad, Fingal Tier, Buckland.
Upper Permian – George Town.
Lower Permian – Preolenna, Mersey, St Marys.

Lowest FC
Triassic – Buckland (52.16%)
Upper Permian – George Town (52.29%)
Lower Permian – St Marys (43.27%)

* Rank determined from fixed carbon percentage on dmmf basis by applying formula

$$FC = \frac{fc \times 100}{100 - (1.08A + 0.55S + M)}$$

fc = fixed carbon from proximate analyses; FC = fixed carbon on dmmf basis;
A = ash content; S = sulphur content; M = moisture;

and from specific energy calculated on mmmf basis by applying formula (after Ward 1984:62, 69)

$$SE = \frac{se \times 100}{100 - (1.08A + 0.55S)}$$

SE = specific energy on dmmf basis; se = specific energy on air-dried coal.

† Coals shown as "Rank Uncertain" are those with fixed carbon less than 69% for which specific energy values are not available.

Source: after Ward (1984: 62, 69).

information to go beyond coal class (see Ward 1984: 70–73). The types of analyses available reflect the limited potential uses of Tasmanian coals.

A couple of points emerge from the recalculated figures. The Lower Permian coals had the lowest fixed carbon content and the smallest range in this content. Upper Permian coals have a somewhat similar range to that of Triassic coals, a range which extends well beyond that of the Lower Permian coals. The Lower Permian coals are from the margin of the Permo-Triassic basin and probably have had less load than later coals from nearer to the centre of the basin. Vitrinite reflectance data are also lower for these Lower Permian coals than for younger coals. Dolerite intrusions occur in the same areas as the Lower Permian coals, but not very close to the seams. The lowest fixed carbon content of Upper Permian coal is also in a coal very close to the edge of the basin and not immediately adjacent to a dolerite intrusion. No common factor can be seen in Triassic coals with fixed carbon below 60%. Coals of anthracite rank in both Upper Permian and Triassic are from seams very close to dolerite intrusions.

Ultimate analyses of coals from a number of seams were also recalculated on a d.m.m.f. basis using the Parr Formula (Ward 1984: 62), this method being the only one usable with the data available. The results are tabulated as table 3 and plotted as figures 5 and 6. Insufficient values are available to allow much interpretation. The carbon content is variable and is clearly influenced by metamorphism, both in Upper Permian and Triassic coals. Lower Permian coals are hydrogen-rich, Upper Permian hydrogen-poor and the Triassic coals mostly intermediate. When the hydrogen/carbon ratio is plotted (fig. 6) none of the Permian coals is revealed as of normal humic type — they are either perhydrous or subhydrous. Some of the Triassic coals are normal but some of these also plot outside the range regarded as normal. The perhydrous coals may be liptinite-rich, as some Triassic coals are known to be, the subhydrous may be inertinite-rich as many Triassic coals are. Only in three cases can ultimate analyses be related to maceral analysis. The Kempton coal, shown to be subhydrous, has an inertinite to other macerals ratio of 2.28; the Mt Nicholas coals, either normal or just subhydrous, have ratios of 1.05 and 1.09

To summarise those properties of interest in utilising the coals, it can be said that the Lower Permian coals have low ash but high sulphur, a specific energy mode at 29 mj/kg and thin broken seams, whereas the Triassic coals have high ash but low to medium sulphur, a specific energy mode at 26 mj/kg and seams in excess of 1.5 m in many places and of 3 m in a few, as well as being more continuous than the Early Permian coals. Upper Permian coals tend to be more like the Triassic than the Lower Permian coals. The main coals of interest, the Triassic are medium-volatile bituminous, but none of them have coking or gas-making properties.

THE MINING OF THE COAL

The Mines

Richmond — ?1804, 1841

The diary of the famous British naturalist Robert Brown, who visited Van Diemens Land in late 1803 and 1804, carries a comment "Top of Grass Tree Hill to Coal Mine" followed by a bearing which indicates that the coal mine was that near Richmond. Brown arrived in the Derwent with Collins about 11 February 1804 and the entry quoted precedes one for 18 February. Perhaps, even at this early date, coal was being mined at Richmond. The household of the Reverend Robert Knopwood evidently used coal from the Coal River as a domestic fuel as early as 1805. Knopwood records in his diary on 14 October 1805, and subsequently on a number of occasions, how coal was brought home from the Coal River.

Major Geils applied for a land grant including the site of the coal mine in 1813. The grant was refused as the site of mineral exploitation was reserved for the Crown. Bigge (1822) reported that no coal was being worked at Richmond.

An outcrop of coal was opened up by a Mr James Bonney on his property near Richmond and the mine offered for sale in 1840 (*True Colonist* 20 March 1840) apparently unsuccessfully. Fifteen months later (*Hobart Town Courier* 4 June 1841: 3) he attempted to float a company to mine the coal. He subsequently repeatedly asked for the loan of Government equipment including "boaring rods" and workers to work his coal (CSO 8/2/295 22 June 1841, 10 August 1841, 13 August 1841) and even offered the mine to the Government (CSO 8/2/295 23 September 1841), an offer which was not taken up. A Government Surveyor, Jones, visited this mine and additional prospecting workings at Jerusalem in January 1844, with a view to the

TABLE 3

Carbon, Hydrogen and Oxygen in Tasmanian Black Coals

Locality	Age	% C	% H	% O	H/C*	O/C*
Preolenna	LP	79.73	6.47	9.96	0.97	0.09
Spreyton	LP	62.55	6.61	28.26	1.27	0.34
Illamatta	LP	70.4	7.4	19.54	1.26	0.21
Cygnet	UP	85.86	4.58	9.88	0.64	0.09
Bruny	UP	73.84	3.86	22.76	0.63	0.23
Catamaran	Tr.	73.04	4.99	21.5	0.82	0.22
Hastings	"	75.91	6.03	18.61	0.95	0.18
Strathblane	"	69.47	5.71	25.24	0.99	0.27
Kaoota	"	64.87	5.69	29.57	1.05	0.34
(=Sandfly)	"	76.34	5.3	18.42	0.83	0.18
"	"	79.65	4.68	16.76	0.71	0.16
Kempton (1983/33)	"	82.7	4.50	10.82	0.65	0.10
York Plains	"	78.73	4.46	17.47	0.68	0.17
Buckland	"	57.65	5.02	37.50	1.04	0.49
Mt Christie	"	77.92	6.02	16.84	0.93	0.16
Merrywood	"	72.26	5.74	22.13	0.95	0.23
Saltwater River	"	80.31	4.41	15.67	0.66	0.15
Fingal	"	80.79	5.38	15.09	0.80	0.14
Mt Nicholas	"	65.31	5.76	29.37	1.06	0.34
" (1984/41)	"	78.3	5.15	14.6	0.79	0.14
" (1984/41)	"	81.6	4.93	11.4	0.73	0.10
Cornwall	"	75.16	5.15	20.07	0.82	0.20
Cardiff	"	69.44	5.63	24.95	0.97	0.27
Jubilee	"	71.45	5.77	22.81	0.97	0.24
Silkstone	"	74.76	5.49	20.23	0.88	0.20
Douglas River	"	73.84	6.13	21.72	1.00	0.22
"	"	72.85	5.72	22.27	0.94	0.23
Dalmayne	"	67.73	5.38	27.7	0.95	0.31
"	"	69.81	5.61	26.21	0.97	0.28
Denison River	"	74.85	5.38	20.77	0.86	0.21
Mt Paul	"	79.39	5.70	16.3	0.86	0.15
Seymour	"	64.28	5.82	30.56	1.09	0.36

* H/C and O/C are atomic ratios.

Sources: Analyses (except those indicated) recalculated from Hills *et al.* (1922: 28–30, table 1) on dmmf basis using Parr formula; Kempton and Mt Nicholas figures from unpublished Department of Mines reports as numbered.

Government taking over the workings. Bonney's mine at Richmond was described as a drift driven for 6 m on the dip of the seam, now full of water and abandoned. The coal was only 150 mm thick, with 1.2 m of shale above the coal (CSO 8/108/2279 2 January 1844). Jones considered that, although the coal was of good quality and situated close to Richmond, mining was unlikely to be profitable because of the water problem associated with the steep dip ("12 inches upon the yard" — approx. 20°).

Macquarie Harbour — 1822

Tertiary coal on the shores of Macquarie Harbour was unsuccessfully worked for a short time. The confession of the convict/cannibal Alexander

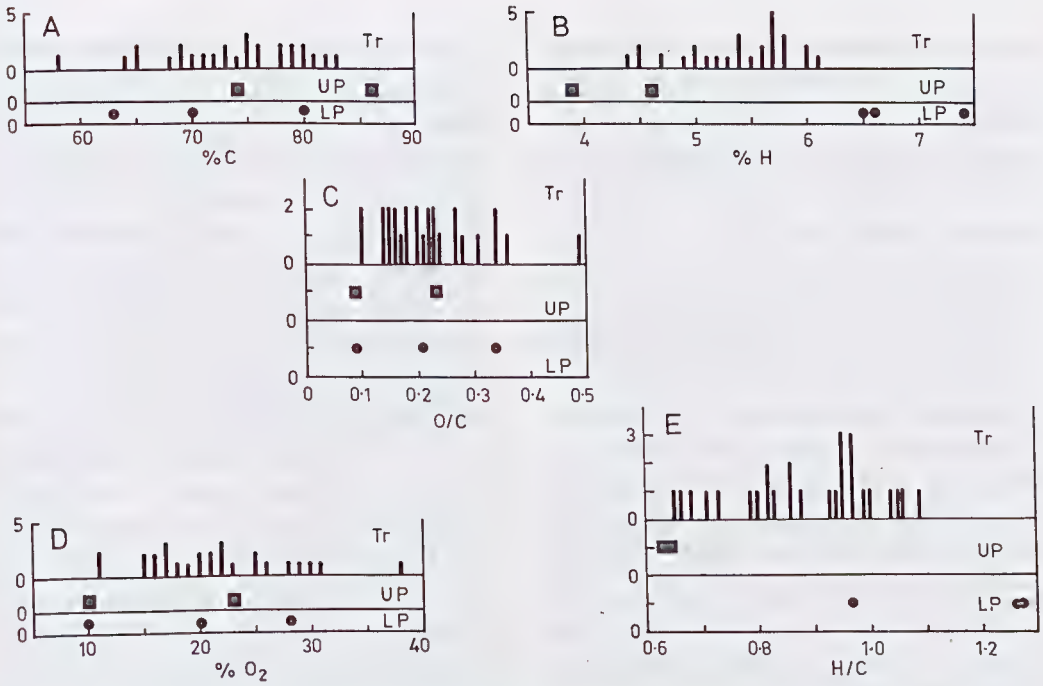


FIG. 5 — Histograms of carbon, hydrogen and oxygen values in Tasmanian black coals; based on values determined on dmmf (Parr formula) basis as shown in table 3. (A) percentage of carbon; (B) percentage of hydrogen; (C) hydrogen/carbon ratio; (D) percentage of oxygen; (E) oxygen/carbon ratio.

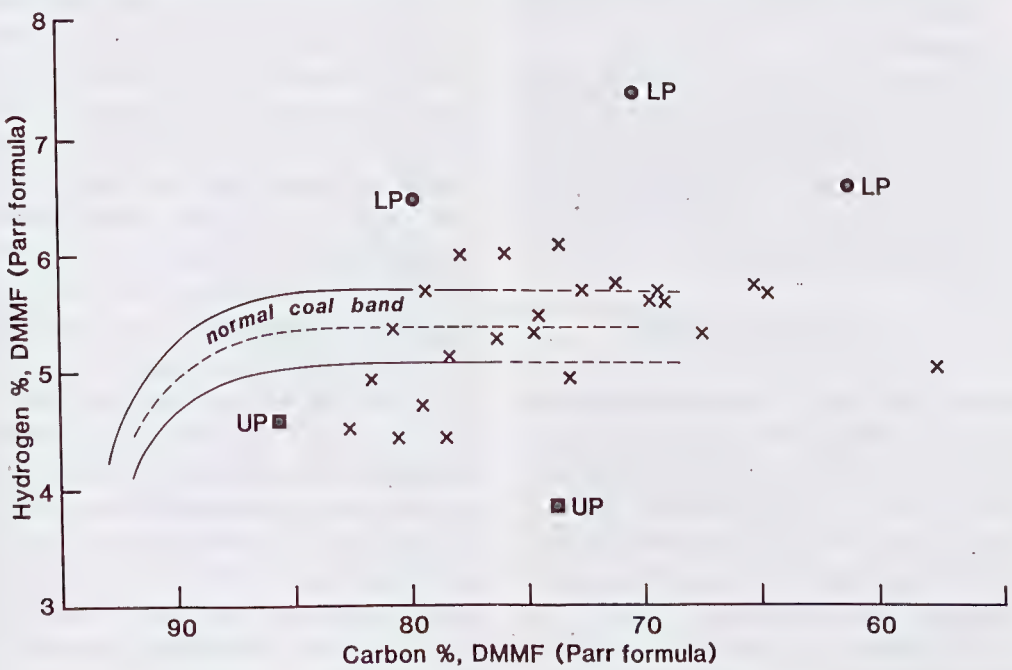


FIG. 6 — Plot of carbon and hydrogen percentages in Tasmanian black coals on Seyler's Coal Chart, based on data in table 3.

Pearce (after whom the Pieman River is supposedly named, as he was a pieman by trade), made to Lieut. Cuthbertson, mentions having to call at the Miners Hut for Robert Greenhill, who was to accompany the escapees as navigator. Pearce, who escaped on 18 September 1822, also mentioned the coal mining when interrogated by the Reverend Knopwood (Sprod 1977):

> "seven prisoners forcibly seized two boats at Kelly's Basin where they were employed in cutting timber under the charge of an overseer, and proceeded to the coal works where they were accompanied by Robert Greenhill ..."

The coal mine was at Coal Head (Julen 1976: 81).

The Macquarie Harbour mining venture was unsuccessful and short-lived. The coal was picked up or dug up on the surface (Julen 1976:22) although a shaft had been sunk in search of coal prior to Pearce's 1822 escape (Dixon Library MS Q168 Evans — Norfolk Island Convict Papers 8). Some, sent to Hobart Town, was not very satisfactory but it was used on Sarah Island (Julen 1976:22). Lieut.-Governor Sorell wrote about it to the incoming Lieut.-Governor, Arthur, on 22 May 1824 (Julen 1976: 19):

> "Good coal on which I relied has not been found, but from indications and from the coal formation in other places it is probable that the failure has arisen from want of scientific research."

It had not been appreciated fully enough that the Macquarie Harbour coal was brown coal not black coal as known elsewhere in Tasmania at that time. Sorell made a comment similar to that above — "the want of professional research had deprived the local Government of the means of working it" — in a despatch to Under-Secretary Horton dated 29 November 1824 (HRA III:583).

Saltwater River — 1833

Development of the mine

The discovery of coal by surveyors Woodward and Hughes near Plunkett Point, Norfolk Bay, early in 1833 (prior to 23 May, O'Hara Booth Journal, Heard 1981: 158), was the result of instructions issued to them by George Frankland, Surveyor-General. His report to Governor Arthur (GO 33/16/264–265) of 29 January 1834 includes the phrase "after a careful search for coal". Frankland's instructions were in turn the result of his commission from Earl Bathurst conveyed through Hay to Arthur (HRA III (5):234).

Woodward was sent by O'Hara Booth, Commandant at Port Arthur, to "open a space into the mine" prior to 15 October 1833, when Booth reported on the coal in a letter (CSO 1/690/15052) and recommended an examination of the seam by a "regular miner" and the use of boring rods. In another handwriting, as an appendix to the letter, seems to be an instruction to be conveyed to the Chief Police Magistrate to use a Mr Lacey. Certainly by 31 October 1833, Matthew Forster, Chief Police Magistrate, was recommending to the Colonial Secretary that Joseph Lacey and four other convicts be sent to begin the mine excavations, Lacey having returned from an inspection (CSO 1/690/15052) of the coal (Forster to Arthur 31/10/1833, TSA). Lacey was "a practical miner at home" (Besford 1958: 136). O'Hara Booth in his journal noted "went to the mine" (19 November 1833) and by December of that year a shaft was down thirty feet (10 m) (Heard 1981: 166). The first shipment of coal from Saltwater River reached Hobart Town in the schooner *Kangaroo* on 3 June 1834. It fetched between 10/– and 19/6d per ton at a time when you could have bought about 40 loaves of bread (each 680 g) for a £1 (TSA Wayne Index "Bread, price of"). The coal was not entirely satisfactory, as a letter from the Survey Office dated 6 June 1835 (LSD 1/79: 24) asked for wood to start the fire because of the stony quality of the coal. It was mostly used as a domestic fuel in Hobart although there were constant complaints regarding its quality. Denison (1870, Vol. 1: 38) remarked that the coal "answers well for the kitchen but is dirty and flies about too much to be used in the sitting room" (because of pyritic layers, Besford 1958).

By 1837 two shafts and one adit connecting with one of the shafts had been dug. Various "galleries" were driven off from the two shafts to provide working places. All extraction was done using the bord-and-pillar method, initially using both shafts and adits for access. Four cells, having the approximate dimensions 1 m × 2 m × 2 m, were dug at the base of one of the shafts, and these nasty "cubby-holes" were used as punishment cells.

The Polish explorer, Dr John Lhotsky, visited the mine in February 1937; in reporting to the Commandant (CSO 5/72/1584), he noted the need for a survey of the mine and for better records (pro-formas of which he submitted), and suggested boring deeper or looking for better coal elswhere.

In March 1837, Sir John and Lady Franklin visited the mine and Lady Jane recorded in her diary a most detailed description of the workings, buildings, jetty and her general impressions of the

place. She noted fires burning at the entrance to the coal mine (possibly these were to assist in ventilation; an old method of mine ventilation was to build a stone chimney and light a fire at the entrance of an adit or shaft, so the fire would create a draught, sucking air out of the adit/shaft and letting fresh air flow into a second entrance). Lady Jane proceeded into the

> "farthest hole in the cliff (an adit) to right straight passage, sides supported by wooden posts, support cross rafters for keeping up flat roof with coal, get on here slightly stooping ... go on 78 yards [70 m] to cached rock, a sort of small hall where at further end on floor is circular shaft to lower gallery with wheel on each side worked by men ..."

Production was then 35 tons per day from two seams. Coal was conveyed from the lower galleries by baskets which emptied automatically into small carts which then ran on rails along the adit to the jetty (Brand, in press).

Early in 1840, Lacey was withdrawn temporarily from the Saltwater River Mine to sink a shaft with other chosen convicts at Southport and again, later in the year, at Recherche Bay, despite O'Hara Booth's plea to Forster that such would lead to loss of production at Saltwater River and a short supply of coal through the winter period (CSO 5/224/5707).

William Dawson (see below), reporting to Josiah Spode, Assistant Chief Police Magistrate, on 21 July 1842 (CSO 22/59/909) made an estimate of the area underlain by coal and the yield (200 000 tons = 203 209 tonnes), although some of that could not be recovered because of danger of collapse of the overlying penitentiary buildings. Because of the water problems then being encountered, and for other reasons, he suggested sinking a new shaft higher up the hill. He drew attention to the "necessity of a survey of the underground works being ... carefuly kept up".

A ten horsepower (7.5 kilowatts) steam engine, designed and erected by Alexander Clark, was installed on 5 August 1841 at a cost of £600 (CSO 22/4/56). Prior to this, coal was raised by a winch which used convict labour (Ford 1932), and two pumps for removing water from the workings were also manned by convicts. The mine headings were only 1.2 m high and the ventilation was poor. The roof, which was composed of shale, was supposed to be left, but was often taken to make the working conditions easier (*Advertiser* 9 August 1839:3).

Until 1840 convicts were sent to work at the coal mine as punishment, although only a small number of those at the mine actually worked underground. From 1840 to 1848 the convicts working at the mine were those on probation, and were released at the end of their probationary periods (Booth 1962). In September 1848 the mine was leased to Alexander Clark and C.M. McShane who were forbidden to use convict labour underground (CGF 10591/4 30 September 1848). In July 1851 James Fulton (who had been Assistant Superintendent at the mine from 1843–48) took over the lease of the mines (CSO 24/–/6216) but this lease was short-lived. The Deputy Commissary (who supplied government departments with coal) wrote to the Colonial Secretary noting that after Fulton's lease had come into effect the Government was forced to take coal from New Town collieries (CSO 24/201/7508). The lease expired in 1856 and the new tender was won by William Nichols and John Thomas (Brand, in press). These two seem to be the only ones among the private owners who failed to "make the mine pay". The old workings were evidently worked out; a new shaft was sunk but no coal was found. The lease was re-advertised on 16 March 1858, and this time James Hurst, a former mine superintendent (see below) was the successful tenderer. The mine closed in 1877.

Some notable men involved at the mine

William Dawson has been noted above as reporting on the Saltwater River Mine. He was a surveyor (probably with some training in civil engineering) and later had other and more sustained contacts with coal mining in Tasmania. After the discovery of coal on the Mersey he was engaged as surveyor and mine manager by the Mersey Coal Company in 1853 and subsequently played a prominent part in mining and other community activities in the Mersey district, especially near Tarleton and Sherwood (Ramsay 1958:121–126). He mined close to Dawson's Siding on the railway line southwest of Latrobe.

James Hurst started work at the Saltwater River Mines as an overseer (while on ticket-of-leave) in December 1840. He was a coal miner by trade, transported for life for acts of highway robbery committed with his father in 1822. Both arrived in Tasmania aboard the *Woodford* in August 1828. Hurst was promoted to the position of Mine Superintendent and was apparently good at his job, as Governor Franklin insisted that William Dawson co-operate and avoid "clashing" with Hurst during the survey of the Mines Dawson was

to undertake. Count Strzelecki spoke to Franklin (CSO 22/59/909: 167) in high praise of Hurst's ability. His work was praised by Commandant Booth, after Hurst repeatedly requested a salary whilst he was a ticket-of-leave man (which was refused by Governor Franklin), then an increase in salary when he was working as a free man after his full pardon came into effect.

When a new shaft was sunk in 1843, Booth wrote (CSO 22/22/880),

> "... and I can only add that no one can deserve more merit for his unceasing zeal and exertion for the public service than Mr Hurst"

Hurst kept the lease of the mine until he died in 1877, when the mine closed. The coal was virtually all worked out, and Hurst had in 1876 taken out leases at Sandfly, ordered a steam engine from the Excelsior Foundry, and quite probably intended moving his mining interest to this new location. The Sandfly venture also folded with his death. Whilst he arrived in chains, James Hurst died a wealthy and respected citizen of Hobart. During his years as a free man, he ran an inn at Swansea (1854), bought the Travellers Rest Inn (at Hobart), built a jetty at Swansea (1855–56) followed by the building of municipal and police buildings (1860–62) before moving to Hobart to live, while one of his three sons saw to the day-to-day running of the coal mine.

Zephaniah Williams, another name first noted in connection with the Saltwater River mine, subsequently had close associations with the coal-mining industry, especially in the 1850's. He was an innkeeper, mineral surveyor and coal merchant before his arrest and subsequent conviction on charges of high treason arising from Chartist plots for an uprising in Monmouthshire in November 1839; his death sentence was commuted to transportation to Van Diemens Land for life. Another Chartist, John Frost, sentenced with Williams, reported in a letter to his son in Bristol that "The Governor told us repeatedly that we (Chartists) were not sent to Port Arthur as punishment, but to fill certain offices..." (*Hobart Town Courier* 4 June 1841: 4) and they seem to have had some privileges. Our next news of Zephaniah is in a letter from William Jones to the Colonial Secretary on 25 January 1844 (CSO 8/108/2279) suggesting that Williams, "now a constable", be employed as an overseer at the Jerusalem Mines. During the interval 1840 to 1849 he pursued a number of occupations and received a ticket-of-leave in 1849. A shaft was sunk near the Cascades Factory in March 1849 (*Colonial Times* 6 March 1849: 2) and subsequently others nearby, all unsuccessful; when later discovery of coal at New Town was reported (*Hobart Town Courier* 29 March 1851: 2; *Hobarton Guardian* 29 March 1851: 3) it was noted that Williams was closely connected with both endeavours. He became co-proprietor with R.J. Collins of the Triumph Coal Mine at New Town (*Hobarton Guardian* 17 September 1851: 1). Governor Denison, in a despatch to Lord Grey on 6 January 1852 (GO 33/75/5), noted that Williams had held his ticket-of-leave with good conduct for two years and had discovered coal in the neighbourhood of Hobart Town; Denison therefore supported Williams' application for a conditional pardon, which was granted on 27 January 1854. Late in 1851, Williams visited the newly developed Mersey field; later he severed his connections with the New Town group and returned to the Mersey as manager, on behalf of a Hobart company of which he was a member, of a mine at Tarleton. He subsequently managed mines in the area, owned a store and a sawmill, and in 1862 became a publican, a business interest he retained until his death in 1874 (Ramsay 1958: 125, 126). It was rumoured (*Launceston Examiner* 24 April 1855) that Williams found the oil shale ("combustible schist", "dysodile", "tasmanite") in the Mersey area in 1851, but this seems unlikely as Mr J.A. Wheeler of Port Sorell sent a specimen of the oil shale to the Royal Society of VDL, which was exhibited at the 9 April 1851 meeting. Williams was probably still active in the New Town area at that time. A.R.C. Selwyn visited the Mersey area in April 1855 (*Launceston Examiner* 24 April 1855: 3) to report on the coal and maintained that Williams was looking for coal beneath marine beds where it was not to be found. As noted earlier, Selwyn was correct for the particular mine but wrong in general. Williams' interest in coal continued into the 1860's as he reported to a Select Committee on Coal Fields in 1864, having been in the Fingal area, St Pauls Valley, Swansea and Triabunna areas at least, in 1862 (Horne 1864).

Southport — 1840

A venture into coal mining was made in 1840 by Charles Swanston and eight others, who formed a syndicate and approached the Government of the day for assistance in sinking a shaft near Southport. The targets of this venture were seams in the Cygnet Coal Measures of Permian age (GO 25/8/76). The proposal by Swanston was that

the Government provide the labour for sinking the shaft and operating the mine, with the company to provide materials; if successful, the company (The Van Diemens Land Coal Company) would lease the mine for 99 years at a cost of 2.5% of the profits (Executive Council Minutes 19 May 1840). The scheme was proposed again in 1841 and 1842 (Hartwell 1954).

The project drew satirical "extreme surprise" from the *Colonial Times* (11 February 1840:4) but the report does not seem to have been accurate, in view of a later letter from Franklin to the Secretary of State. Government favouritism was alleged in the same paper a week later (*ibid.*: 4) and a statement made that the overseer (Lacey) and four of the best miners from Saltwater River were working at Southport. This statement seems to be borne out by a letter of 10 February from O'Hara Booth to Matthew Forster (CSO 5/224/5707). The Lieut.-Governor (Sir John Franklin) noted in his letter to the Secretary of State (13 June 1840; GO 25/8/76) that after receiving the proposal he caused an investigation to be made, and the work noted in the *Colonial Times* may well have been that investigation.

As the report was favourable, the Governor had the matter considered in the Executive Council and granted a lease for 21 years (GO 25/8/76). A shaft was sunk in 1842. Some 1300 tons of coal were brought to the Hobart Market (*Colonial Times* 17 May 1842). The Government Surveyor, Jones, claimed that most of this coal was obtained from the outcrop on the foreshore and not from any regular winning, so the coal was dirty (CSO 8 /108/2279 13 July 1844). The mining operation was not profitable and collapsed, owing the Government £4316 (£1 could buy about forty loaves of bread at that time) for the services of convict miners and an overseer, and for tools and stores supplied by the Government (GO 1/54 9 May 1844: 90).

The company had a brief period of paper prosperity in 1840, when the shares rose from 10/– sterling to £10 each. However, on the collapse of the company, the shareholders could not be traced and the Government was forced to forfeit the sum owing (GO 33/78 31 March 1853:713–717). The affair became known as the "Southport Swindle" (Booth 1962). Swanston was, at the time, one of two Attorneys-General and was later involved in coal mining on Schouten Island as well as many other industrial ventures.

Jerusalem (Colebrook) — 1841

As early as 1823 the presence of coal at Jerusalem was known (Besford 1958), and in 1831 this was being used as a reason for constructing a road from Richmond to Oatlands (James Gordon to Lieut.-Governor Arthur 4 November 1831: GO 33/21:372–373). James Clare rediscovered coal near Jerusalem (at Coalmine Bend) in 1841 (LSD 1/28/458 August 1841) and was employed to sink a trial shaft there on behalf of the Government (CSO 22/47/190 5 December 1841).

The Government Surveyor, Jones, was sent to inspect both the Richmond and Jerusalem workings in January 1844 and at Jerusalem recorded a seam 1.2 m thick, cropping out in Wallaby Creek (a tributary of the Coal River), and three other outcrops, one of which had been opened by an adit driven for 90 m and by a shaft 12 m deep (CSO 8/108/2279 15 January 1844). As a result of Jones' inspection, the Government decided to open up the Jerusalem mine and work started in March 1844 (CSO 8/10/2279 11 March 1844). Jones reported that two more seams had been opened up by August 1844 (CSO 8/108/2279 10 August 1844) but the quality of the coal was apparently too poor to warrant further investigation and the operation closed later that month (CSO 8/108/2279 21 August 1844).

Zephaniah Williams had harsh words to say about the Jerusalem coal he was instructed to inspect in 1862, writing to Falconer of the Public Works Department (Horne 1864):

> "...I deem it incumbent to inform you of the state of the coal I am instructed to get 10 tons from. The seam is altogether three feet thick; but it will scarce produce two feet of clean coal. I never was more deceived than today; for on cutting into the seam I found it full of hard stone and of iron pyrites distributed throughout which in reality makes it good for nothing except for kitchen purposes, as it is quite impossible, without breaking the coal to pieces, to clean it. This is the coal there has been so much writing in praise of the most worthless seam of coal I ever saw. It contains some good coal. However I shall continue working it till I hear from you. In consequence of so much stone and iron pyrites scattered through it, it is very expensive getting and we can scarcely get tools to stand the cutting, in fact it is a seam that never will be worked for any purpose. Awaiting your answer with the utmost impatience."

No mining activity resulted from this 1862 inspection. However, in 1879 work began again at Coalmine Bend, the mine being known as the Jerusalem colliery. This operation closed in 1890, although a small quantity of coal was extracted in 1894.

Closer to the town of Colebrook, a second area was worked from 1892 to about 1921. The mines were Bayntons (1892–97), Glen Leith (1902), Marialva (= extended Glen Leith workings 1902–1904), Colebrook (1911) and Tasma (formerly Bayntons, 1919–1921) (*Dep. of Mines Ann. Repts* 1901–21, *Railways Ann. Repts* 1901–21, *Dep. of Mines Underground Plans* 282, 223, 380).

Schouten Island — 1843

John Woodward Graves (writer of "D'y ken John Peel") attempted unsuccessfully on 23 July 1840 to obtain from the Surveyor-General, Capt. Boyd, rights to coal on Schouten Island (LSD 1–46: 585–586).

Three years later Governor Franklin granted to Jesse and Isaac Garland a lease to mine coal on Schouten Island for six months from 16 September 1843 (CSO 22/84/1807: 149). The lease was extended for an additional six months, but a further extension was refused on the grounds that the Government planned to set up a probation station on the island (CSO 22/84/1807: 165–167) to work the coal. However the probation station was not built. Some 200 tons of coal from Schouten Island were on sale in Hobart in September 1844 (*Colonial Times* 27 August 1844). Milligan (1849: 8–9) commented on the mine workings as far as he was able in view of the deterioration.

The Australian Smelting Company was formed in August 1848 by Charles Swanston (of the Southport coal venture), with the object of procuring copper or other ore from Adelaide to be refined in or near Van Diemens Land. The company had a local board of directors and a committee in Adelaide (*Hobart Guardian* 3 July 1850). In 1848 offers were made by South Australian smelting companies to take 25 000 tons (25 400 tonnes) of coal per year for £1/1/– per ton (Denison to Grey 18 May 1849; £1 would then buy about 70 loaves of bread).

Swanston's smelting company formed the Schouten Island Coal Company in response to this offer, and began mining even before a lease was issued. Sixty tons of coal from Schouten Island were unloaded in Hobart in November 1848 (CSO 24/78/2496). A lease to mine coal for 21 years on payment of a royalty of 2 pence/ton (i.e. 1/120 of £1/ton) was issued in December 1848. Interest in the venture declined, and no mining operation actually started in earnest.

Douglas River — 1848

With the offer from the Adelaide smelting companies, enquiries were made about coal south of the Douglas River, found by the Garlands in 1843. Governor Denison offered this coal on the same terms as the lease for the Schouten Island coal (Denison to Grey 18 May 1849).

Dr Joseph Milligan, who had inspected the Tasmanian coalfields in 1848 (Milligan 1849), set up the Douglas River Coal Company in May 1849 to exploit the seams south of the Douglas River. Under the terms of the lease, the payment of 2 pence/ton royalty was to be used by the Government to erect a wharf at Bicheno and lay a tramway to the mine (CSO 24/104/3280). Work commenced close to the Denison Rivulet, about 1.6 km from the sea. Two seams were mined from two shafts for a short time. Transporting the coal to Bicheno (a distance of 6.5 km) was very costly, and after 800 tons had been raised, interest was transferred to an area closer to the coast (near Old Mines Lagoon), where four shafts and a number of bores were sunk. These workings were known as the Outer Mines (Gould 1861). Coal from this area was on sale in Hobart in 1850, when ten tons were sold by auction (*Hobart Town Courier* 30 October 1850).

The company spent large sums building the tramway from Bicheno to the mines, as the Government failed to complete the job. The tramway was opened in December 1854. A 20 horse-power (14.9 kW) engine was erected in 1855 at the Outer Mines (Selwyn 1855). Despite the substantial investment, production was small (100–200 tons per month) and in 1858 the company failed (*Hobart Town Courier* 8 March 1858). Twenty-one young English colliers brought out especially to work the mine found their services not wanted (*ibid.* 2 March 1858).

Dr Milligan did not have an unruffled career as Chairman and Manager of the Douglas River Coal Company. He seems to have had technical if not also personal disagreements with one of the superintendents at the mine, J.Thomas. Thomas (1855: 1–TC622–33 THO) referred to the Chairman's "idiotic and impractical notions" as the cause of the Company's unsatisfactory financial situation. He maintained that Milligan had caused to be done more boring and shaft sinking than necessary and implied that Milligan did not

understand the geology. In view of Milligan's published works on coalfields and his appreciation of the effects of faulting and dolerite intrusion on coal distribution that implication can be dismissed. On the other hand, if Thomas' statements about managerial matters not related to the geology are true, Milligan was not a good manager. At the Annual General Meeting of the Company, as reported in the *Hobarton Mercury* of 3 September 1855 (p. 2), there was, after the main business, a "desultory and somewhat personal discussion", a motion for the dismissal of Dr Milligan, followed by notice by Milligan's intention to resign and a vote of thanks to him for his "gratuitous services"!

New Town — 1851

Although coal had been known in the New Town area since 1823 (see earlier), it seems no mining took place for over a quarter of a century. A letter to Lieut.-Governor Arthur from a Mr Roberts (5 September 1831: CSO 1/120/3024) hinting at the need for Government finance to develop the coal received a cool answer, Arthur commenting

> "it does not appear that mines could be worked to advantage by the Government ... I would gladly give encouragement to any private speculation...".

Mining in the New Town area began early in the 1850's (*Hobart Town Courier* 9 August 1851). Boyes noted in his diary for 19 April 1851 that he looked at the new mines (Boyes, *R. Soc. Tasm.* MSS R.S. 25/2C12). By July 1851 coal was being worked at Newlands (*Proc. R. Soc. VDL* II(1): 151) and other shafts had been or were being sunk. Zephaniah Williams discovered coal on Captain Spottiswood's property at New Town (*Hobarton Guardian* 29 March 1851: 3). In the *Hobart Town Courier* (9 August 1851: 3) it was announced that the first load of coals from the shaft sunk by Mr Luckman at New Town had reached the town three days earlier. Just over a month later another source of coal (The Triumph Coal Mines) became available to the townspeople (*Hobarton Guardian* 17 September 1851: 1); New Town was the site of the mine, Williams and Collins the proprietors. This same Collins petitioned the Lieut.-Governor, Sir William Denison, on 27 January 1853, that a survey be made to "ascertain the extent of Mr Luckman's trespass" on the property rented by Collins from the Government (CSO 24/213/8097). The report on the trespass (CSO 24/213/8097) was inconclusive.

Later, interest lapsed and the activity did not last. During the 1870's another burst of interest in coal mining occurred and a few small mines were opened (Thureau 1883a). Coal was sold for domestic purposes. The seams mined were very thin, and the quality of the coal was apparently poor (Krause 1884).

Hobart newspapers of 1 June 1897 recorded that mining had started again at New Town (near the top of Elphinstone Road) after an interval of fourteen years, and production records show that some coal was mined from the old Enterprise Mine in 1911 (30 tons) and 1912 (25 tons).

Mersey Field — 1853

The early history of the Mersey field has been dealt with at some length by Fenton (1881: Chapter XI) and by Ramsay (1958: Chapter VIII). A discrepancy will be noted between these works as to the date of discovery (1850 — Fenton: 1851 — Ramsay). Mr B. Cocker, one of the discoverers according to Fenton, did not reach Tasmania until January 1851 (*Launceston Examiner* 8 January 1851: 10). The earliest unequivocal evidence is that a letter from the Assistant Police Magistrate at Port Sorell, J.A. Wheeler, concerning discovery of coal between the Don and the Mersey, was read at a meeting of the Royal Society of VDL on 12 March 1851 (*Proc. R. Soc. VDL* II(1):141–142). On 31 March 1851, Joseph Milligan was instructed to examine the find (CSO 24/261/5844) and by 14 May was able to exhibit a specimen of coal from the Don River and state the thickness of beds and relative position of the strata to a meeting of the Royal Society (*Proc. R. Soc. VDL* II(1): 147). He read a full report (dated 11 June 1851) to the Society on 9 July (*Pap. Proc. R. Soc. VDL* II(1): 90). The report by Crompton (*Launceston Examiner* 14 April 1856) of discovery in October 1851 is clearly erroneous on this point. Burns (1963, 1964: 88–103, 105–114, 222–245) and Dix (in Jennings 1979: 105–109) have given further information on the later history of mining in the field.

Mining started in the Bott Gorge area, but finished there in 1857 after massive expenditure on infrastructure and the spending of £20 000 on "fruitless endeavour". Two mines have operated in the Denny Gorge, seven near Tarleton, three at East Spreyton, five at West Spreyton and two near Sherwood, one each at Tugrah, near Caroline Creek, and at Nook, and fourteen near Dulverton. Most of these mines were worked for very short times and employed 2–4 people

each. The last mine to close was the Illamatha No. 2, in 1962.

Seymour — 1861

In 1861 mining began at Seymour, north of the ill-fated Douglas River Coal Mining Company's workings near the Denison Rivulet (CSD 4/6/40 11 December 1861). A.H. Swift formed the Seymour Coal Mining Company in 1863 to mine coal, followed by the Australian Coal and Kerosene Company in 1868, with the aim of retorting kerosene from the "slack" (waste) coal produced from mining. Some 2700 litres of oil were retorted from the coal and sent to Melbourne to be refined (*Tasmanian Times* 18 June 1868); this suggests that some of the coal was alginite or liptinite-rich. Vast sums were expended on the building of a railway, storage bins and a long jetty. The first phase of mining lasted 17 years (Hills *et al.* 1922).

A new company, the Seymour Coal Mines Ltd, operated the original mine from 1923 to 1931. A dip tunnel was driven to intersect the old, masonry-lined circular shaft of Swift's mine. This enterprise collapsed when the 400 m long loading jetty was partially demolished by a storm in 1931. The dip tunnel was de-watered in 1959, and the coal mined was transported to St Marys by road. This venture closed in 1964.

In 1890 the *East Coast Harbour and Coal Company's Act* was passed by Parliament, allowing that company leases for 60 years for coal, stone and clay in return for the building of a railway from Seymour to Bicheno. Very generous rights to water, timber and minerals were included in the Act, but the venture failed; the railway was not built and no coal was mined.

Fingal — 1864

At Fingal, southwest of Mt Nicholas, coal had been discovered in the 1840's (Milligan 1849) but no mining started. The Government of the day financed the digging of an adit in 1864 (*HAJ* 1867(95): 7). Mining on a small scale continued intermittently for some years. Activity was renewed in 1920 when the Fingal Coal Prospecting Syndicate drove two adits into the outcrop of the Duncan seam on Cat and Kitten Creek. These workings were acquired in 1942 by H.J. Yeates, who opened the Fingal Colliery. The Duncan Colliery opened adjacent to Yeates' in 1945 and the Tasmanian Mine opened in 1954, on the same seam and adjacent to the Fingal Colliery; work continued here until 1957. Minor activity in 1962–63 was halted due to poor ventilation.

The Fingal Colliery closed in 1965, but was re-opened in 1969 by the management of the adjacent Duncan Colliery, and the Fingal (Cat) tunnel was re-timbered to provide access to the Duncan workings following the closure of the Duncan tunnel. The Duncan Colliery is still in operation and in 1985/6 produced 287 000 tonnes of coal (run of mine), employing 80 men.

Cygnet, Bruny Island, Gordon — 1879

At Cygnet, on the slopes of Mt Cygnet and Mt Heeney, small-scale mining began in 1881, and continued in a haphazard and intermittent fashion until the 1940's. The Cygnet coal is of Late Permian age, as is the coal at Adventure Bay on Bruny Island. A very thin seam, approximately 0.5 m thick, was worked from a series of shafts and adits by W. Zschachner over the period 1879 to the early 1890's at Adventure Bay. Zschachner had previously held mining leases in the New Town coalfield. At Gordon, a Mr Abbot opened up an outcrop of coal on the foreshore (EN 195100), calling the adit the Rookwood Coal Mine. Abbot tried to interest the Victorian Chamber of Commerce in his coal (LSD 1/48/310) and complained bitterly in 1879 that he could not compete with the mining at Adventure Bay (LSD 1/48/214).

Sandfly (Kaoota) — 1876

James Hurst, lessee of the Saltwater River Mine, took out the first lease in the Sandfly area in 1876. With his solicitor, Lucas, he petitioned the Government (*HAJ* 1877 (33): 28) asking to be given land in return for building a tramway to North West Bay. The coal was opened up by means of an adit, work on the tramway had started and a locomotive had been built by Clark at the Excelsior Foundry especially for the project when Hurst died in July and the project ground to a halt. Prospecting work continued for years and in 1906 an extremely elaborate tramway was built from Kaoota to Margate by the Sandfly Colliery Company; it had ten large wooden bridges in a distance of 19.5 km (Whitham 1973). This company collapsed in 1907, having produced only 8500 tons of coal. The tramway was taken over by the Tasmanian Wallsend Colliery Company which operated the Wallsend Colliery until 1910. Since then, a number of syndicates have worked the field, usually calling their workings "the Sandfly Colliery". New adits were dug as old ones were abandoned and the name was transferred to the "new workings". The last mine in this field closed in 1971 (Threader 1972).

Avoca area — 1882

Coal was discovered in the Avoca area before 1845 but the first lease issued was for an area on the headwaters of Storys Creek (to J. Lamont in 1864); however, no mining followed. An adit was dug into this seam in 1882 by a Mr R. Stevenson (Dickinson 1945), but the distance from Avoca was too great for the venture to be successful. A thin seam of coal was found near Mangana (in the Mersey Coal Measures correlate) during shaft sinking for gold in 1863.

Around the slopes of Mt Christie coal was found in 1902. Minor prospecting workings known as the Buena Vista mine later became the site of the Excelsior (Stanhope) colliery, which operated from 1923-57. Extraction was mostly by the bord-and-pillar system, although the longwall system was adopted briefly in 1944. In 1960 a bushfire swept across the mine site, and the seam outcrop at the portals caught alight. The old workings are still smouldering, and parts of the ground surface over the mine workings have collapsed. The New Stanhope Colliery, 1.3 km north of the (old) Stanhope, opened in 1957; a washing plant was installed in 1959 and mining continued until 1973. The Mt Christie Colliery was opened in 1959, in the vicinity of older prospecting adits on the southern flank of Greenstone Hill; it produced about 1800 tonnes of coal per year, but closed in 1965. Recently a new mine has been opened in this area, the Fenhope Colliery, which opened in 1980 close to the (old) Stanhope workings. The mine is owned and operated by Mr D. Fenton; the seam is 3.6 m thick and mining is all done by hand, the coal being wheeled along an impressive wooden gantry to a large wooden storage bin.

A reward lease was issued in 1917 to J.B. Dean and F.R. Davis for discovery of coal near Coal Mine Crag on the Ben Lomond Plateau; this coal has been "mined" by skiers for use in nearby huts.

York Plains — 1883

Coal in the lower Midlands area was described by Gould (1869). Mining at York Plains started around 1883 and continued until 1947. The coal was sold mainly for use in hop kilns. Mining was done by hand on a modified (step) longwall system.

Mt Nicholas Range — 1886

While coal seams had been known to occur in the Mt Nicholas area since the 1840's, no real mining occurred there until 1886. Minor prospecting works extracted some coal in the 1840's and tests of the coal were made by the railways in the early 1880's. However, high costs of transport to a suitable market precluded this field from being worked, until a railway line from St Marys to Conara (then known as Corners) was opened in June 1886. The Mt Nicholas area is the premier coalfield in the State, and mining has been virtually continuous in this field since 1886, when the Cornwall Colliery was opened by the Cornwall Coal Company. Two years later the Mt Nicholas Colliery was opened nearby by a rival company The Mt Nicholas Coal Co. Pty Ltd; having been bought by the Cornwall Coal Co., it closed in 1958, the Cornwall Colliery closing in 1964 due to loss of markets. The Jubilee Colliery, much smaller than the first two mines, was worked from 1897 to 1902 and from 1920 to 1960, and the Cardiff from 1901 to 1914. In 1980 the Cornwall Coal Company opened the Blackwood Colliery, close to the old Cornwall workings. The Blackwood Colliery produced 202 000 tonnes of run of mine coal in 1985/86. A new portal west of the main one and known as the "Blackwood West" opened in 1988. A small area of coal was removed by open-cut means to ensure that the portal would be started in firm, unweathered ground.

Hastings — 1888; Ida Bay — 1892; Catamaran — 1900: Strathblane — 1910

Coal has been known in this general area since 1793 (South Cape Bay) and some workings on the northeastern shore of Recherche Bay were noted in 1838 (see earlier). It seems likely that Lacey, Superintendent at Saltwater River, did open a shaft in the area late in 1840, despite O'Hara Booth's plea to Matthew Forster that his withdrawal with that of other experienced miners would result in loss of production at Saltwater River and a short supply through the winter period (CSO 5/224/5707). An analysis of coal from a small mine at Hastings was given by Johnston (1888). Prospecting at Hastings continued until 1923 when the lease expired.

A small mine was worked at Ida Bay in 1892 as part of a cement-making project (Twelvetrees 1902c). The project did not eventuate and the mine quickly closed. At Catamaran, south of Ida Bay, coal was discovered in 1900. A number of companies worked mines in this field, the last closing in 1939 (Whitham 1983). Most of the early work in this field consisted of the construction of enormous bins, expensive tramways and jetties, leaving little capital for mine development proper. Most of the early investing companies in this area

collapsed due to over-spending on infrastructure. Workings in this area included Hoods (1900-10), James (1910-12), New Main Shaft (1913-14), Mackenzie (1923-30), Ribbon (1931-34), Anthracite (1927) and Stronach Tunnel (1934-39).

Coal was discovered at Strathblane, north of Ida Bay, in 1908. Prospecting work was carried out for some years, and a small-scale mining operation extracted coal from 1926 to 1933. The average seam thickness was about one metre (Keid 1952).

Preolenna — 1903

Very thin seams of coal were mined at Preolenna, on the northwest coast, early this century. Following the discovery of outcrops of coal in 1903 by track-cutters, small-scale mining of the coal occurred intermittently from 1921 to 1931, with two mines, Preolenna and Torbanhill (Meunna) being opened. The Meunna Mine was, in 1919, a series of prospecting workings called "The Great Fitzroy Coal Mine". The use of the name "Torbanhill", reflects on the boghead nature of the coal, there being a similarity with the oil shale of Torbane Hill, near Edinburgh, Scotland. Considering that the seams were no more than 0.5 m thick and dipped at up to 25°, the attempts at mining were certainly optimistic. The coal is of Early Permian age and the Preolenna Coal Measures in which the seams occur may be correlated with the Mersey Coal Measures further to the east.

Dalmayne — 1914

The Dalmayne coalfield lies southeast of Mt Nicholas. Outcrops of coal had been known since before 1860 (Gould 1861a) and reward leases were applied for but not issued in 1887. No mining eventuated until the ambitious Dalmayne Colliery Company was floated in 1914. The company built an aerial ropeway from the mine site to Piccaninny Point, a distance of 5.5 km. A jetty 180 m long was built at Piccaninny Point for loading the coal. Substantial mine development work occurred and the mine was officially opened by Sir Elliot Lewis, Minister for Mines, on 24 August 1917. However, a shortage of boats for shipping the coal (owing to the war) hampered progress and in 1918 the jetty was washed away in a storm. The mine was forced to close, but reopened in 1939 under new management. Coal was transported by road to St Marys until the operation closed in 1953.

Langloh — 1938

In the Derwent Valley, near Hamilton, the Langloh (Lawrenny) Colliery began operations in 1938, continuing until 1963. Coal had been known from this locality since 1849 (see appendix 1) and minor prospecting activity occurred in the 1890's (Montgomery 1894). Small reserves of coal adjacent to the old colliery and suited for open-cut extraction have been evaluated recently.

Merrywood — 1945

Coal was discovered at Red Rock, near Merrywood, by Zephaniah Williams in 1864 and rediscovered in 1909. Mining eventually began at Merrywood (the Merrywood Colliery) in 1945, with coal being extracted by both underground and open-cut methods until 1963. A washing plant was installed in 1957 and coal hauled by road to the railway at Avoca. In recent years open-cut extraction on a small scale (1500 tonnes/week) has resumed for a few weeks each year; this activity is likely to be for a limited period only.

SUMMARY OF THE INDUSTRY

Some quantitative aspects of the mining industry are presented in a series of graphs and a table. The distribution of the discoveries of coal in space and through time is shown in figures 1 and 2 and has already been discussed. Not unnaturally the distribution of time of initial opening of mines is delayed relative to the discoveries but, like the distribution of discoveries, shows some peak periods (fig. 2 A(iii), B(iii) and appendix 2).

The first period of intense activity was from 1840 to 1859, the second in the 1880's, and there was a long third period from 1900 to 1939, with the highest rate per decade in the 1930's. The first period covered a time of general population increase (with a distinct slump in the 1850's due to emigration to the Victorian gold fields (Johnston 1901)). The Government saw the possibilities of export, such as occurred with New South Wales coal, and of useful employment of convicts. During this period, and earlier, convict labour was used in mines at Macquarie Harbour, Saltwater River, Jerusalem (Colebrook) and Schouten Island, with minor use at Southport and Recherche Bay. The increasing use of coal as a fuel for steam locomotion accelerated the opening of mines. Thus, the first steamer using coal plied the Derwent River as

a ferry from Hobart Town to Kangaroo Bay beginning in 1832 (*Colonial Times* 10 September 1832). A vessel such as this, with an Australian-built marine engine, which had started on the ferry run in 1834 (*Colonial Times* 12 September 1834), drew admiration from Charles Darwin when he crossed the river early in February 1836 (Barlow 1933: 388–389). The colonisation of Port Phillip provided, at least temporarily, an opening for export sales; these reached their zenith in 1858 when 2670 tonnes were exported, almost 96% of it from Launceston and probably originating in the Mersey fields, where eight companies were supplying coal to the Melbourne market (Booth 1962:37). A peak in the number of producing mines was reached in 1855 (fig. 2C). Another factor increasing the rate of opening of new mines or reopening earlier mines was the demand for coal for smelting copper in South Australia. This demand led to the establishment of a company, Australian Smelting and Coal Company, in 1848, but this company was not very successful in mining coal (Booth 1962: 29).

The population of Tasmania did not rise as rapidly in the 1860's and 1870's as it had previously. Unlike the situation in other parts of Australia, which experienced boom conditions, stagnation affected Tasmania (McGhee 1969: 138). Further, Tasmanian coal lost the Victorian and South Australian markets in competition with cheaper and better New South Wales coal (Booth 1962: 93). The number of mine openings dropped after 1860, but the number of operating mines gradually rose from 1860 to 1874 (fig. 2C). The effects of the opening of the Launceston and Western Railway in 1871 and of the Hobart to Launceston Line in 1876 caused some increase in mine openings even prior to the opening of the Conara Junction to St Marys line in 1886. The latter had a major effect as this line provided access to the Fingal-Mt Nicholas fields with the thicker and more continuous seams. More mines were opened in the 1880's than in any prevous decade and the total number of mines operating reached another peak in 1889 (fig. 2B(iii), C). Stagnation in the Tasmanian economy in the 1880's was followed by Australia-wide depression in the 1890's. The number of mine openings and the total number of mines fell in the ten years ending in 1900. Despite the general depression the mining towns of the South Esk Valley — Fingal, Mt Nicholas, Cornwall and St Marys — grew (Blainey 1954: 65) and the Huon area did well. In the Huon the first timber mill had opened at Recherche Bay in 1860 (*Centenary of Settlement in the Huon*. Huon Newspaper Co., Franklin 1936); there were many mills in the area in the 1880's and in 1890 there were 17 sawmills in the Franklin district (*Walch's Almanack* 1890: 328). Here, the activities associated with milling led to the discovery of coal outcrops and the excellent steamer services provided accessible transport for any coal produced. New mines were opened near Cygnet, Catamaran, Hastings, Ida Bay and Strathblane from the late 1870's to the early 1900's. Thus there were more mines producing in Tasmania in 1910 than at any previous time (fig. 2B(iii), C). The number of mines open and the number of new mines fell over the war period and immediately thereafter. The 1920's were years of depression in the coal industry in Australia and production remained low. Tasmania was not so seriously affected as other parts of Australia, due to a local high price of coal and a major industrial strike in New South Wales (Shaw & Bruns 1947: 90). The depression of the 1930's was a period when the rate of opening of new mines was the highest in the history of Tasmania up to and including the present day. The peak in the number of mines was reached in 1938 (fig. 2C). Most of the mines opened (or reopened) in the 1930's had short life spans (fig. 7B). At least ten small mines opened and closed in the Mersey coalfield alone. It seems likely that the peak of openings in this decade resulted from men put out of regular work seeking a paying "fill-in" activity. Production (fig. 9) did not increase greatly compared with the massive increase in the number of mines. After 1940 the rate of opening of mines and the number of mines operating has decreased more or less consistently and markedly. Part of the decrease can be attributed to the progressive replacement of coal by oil, and the opening of new mines in the 1980's results from the high price of oil. Part of the decrease (fig. 2A(ii), C) can be attributed to the high capital outlay needed in recent years to open a mine. No longer are a pickaxe and shovel, a light, and a horse and cart or small truck generally enough.

It is interesting to examine the longevity of Tasmanian coal mines as revealed from offical production figures (fig. 7). As seen from figure 7A, almost 40% of mines have recorded production for only one year and 63% have had productive lives of five years or less. The decades ending 1910 and 1940 (especially the latter) were particularly notable for the short lifespans of mines started in the decade. Two fields stand out as having more longer lived mines than others (fig. 8) — the Mersey field working on low ash, high specific energy Lower Permian coals, and pre-eminently the

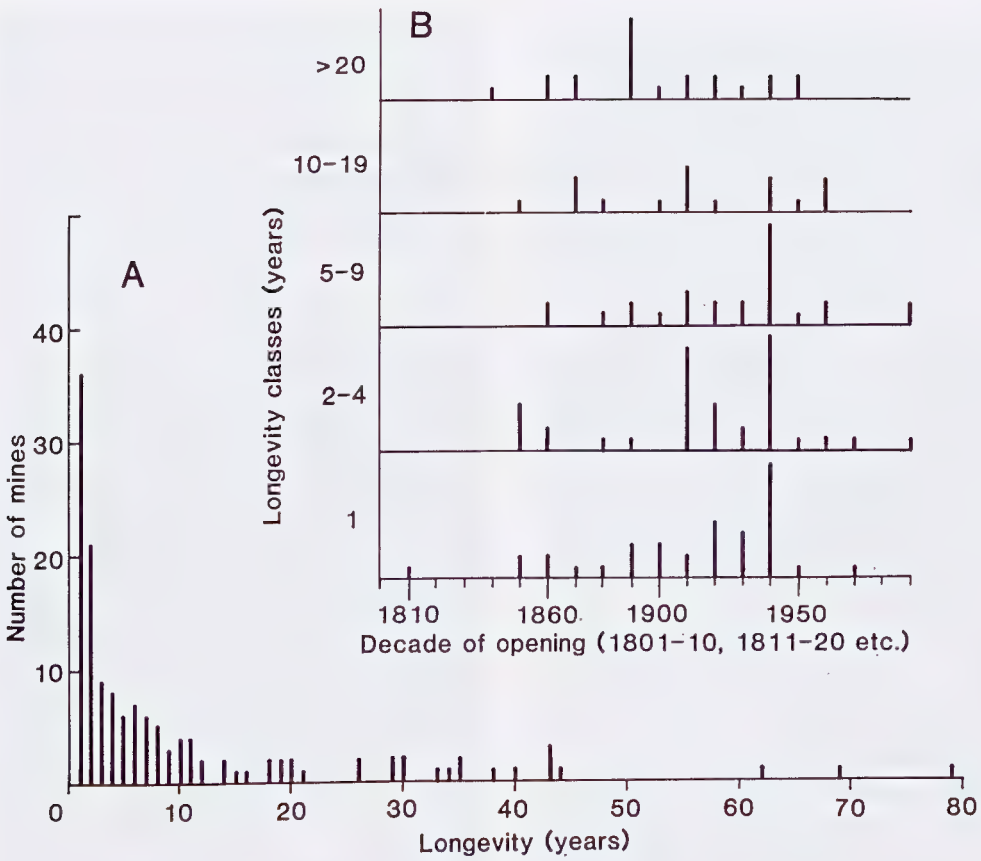


FIG. 7 — Longevity of Tasmanian coal mines; based on information in figure 6. (A) distribution of longevity in years; vertical bars show number of mines having longevity indicated by position on horizontal axis; (B) distribution of longevity of coal mines according to decade of opening.

Fingal-Mt Nicholas field working on thick and more continuous seams of Triassic coal, albeit with high ash content and relatively low specific energy. The Cornwall Mine has had the longest working life (about 78 years) and the nearby Mt Nicholas Mine one almost as long.

Production and Employment

Booth (1962: 98) advanced a number of factors affecting a coal-mining industry. The factors include coal quality, the size, continuity and position of seams relative to the ground surface, a large market and cheap transport. Lack of several of these factors has ensured that the Tasmanian coal-mining industry has never been a major one in Australia-wide terms, as shown graphically for the period after 1900 by Elford & McKeown (1947: fig. 5). The Mersey coals are approximately equivalent in quality to those of New South Wales but the seams are thin and discontinuous. The seams of the Triassic coals are thicker and more continuous than those of the Mersey but the quality is not so high. Mining conditions are ideal in few places, faulting and dolerite intrusion causing difficulties. Initially transport was a difficulty but this factor was partially overcome with the advent of steam-driven vessels and railways. Even now, transport can provide problems. The local market for coal has always been small and export has been limited because of competition, especially with coal from New South Wales which has had the dual advantages of a much larger home market and

better quality than Tasmanian coal and also, it might be said, better mining conditions.

Coal production has not always paralleled either the rate of discovery or mine opening, or the total of miners operating. The first peak in discovery and exploitation in the 1850's preceded offical records. It is known that production reached a peak of 10 600 tonnes at Saltwater River in 1840 (Booth 1962: appendix A) and that coal exports reached a maximum of over 2670 tonnes in 1858 (Booth 1962: appendix B). Coal production, like discovery and exploitation, stagnated or dropped slightly from 1866 to 1886 after which it rose to a peak in 1889–90 (fig. 9). Subsequently, the depression of the 1890's is reflected in production decrease and the recovery therefrom in rising production rates until 1910–11. The rise in production paralleled the rate of discovery and of mine openings and the peak corresponds to the peak in the number of mines open at the end of a decade (fig. 2B(iii), C). The activity in the industry in the late 1920's and early 1930's is reflected by production figures as well as mine openings and mines operational (fig. 10). After 1940 there is little relationship between the production figures and the factors operating earlier. Increased industrialisation in the State led to increased demand and production until the late 1950's, after which replacement of coal by oil as a heating fuel in many industries reduced demand and production in the mid-1960's to the lowest figure since the 1920's. Increase in the price of oil reversed the trend away from coal burning, and production has increased very dramatically since. This increase, and the possible need to supplement hydro-electric generation of electricity, fostered work by the Geology Section of the Hydro-Electric Commission (H.E.C. 1967) and the intense exploration programme of the 1970's and early 1980's (*Tasmania, Director of Mines Reports* 1974 *et seq.*).

It will be seen from fig. 10 that the number of operating mines since 1900 has not been high and that many of the mines employed only a few men. A tendency for the number of mines employing more than 16 people (fig. 10C, D) to rise until the early 1960's is also revealed, i.e. the number of "big" mines increased. Rises in production after the low of the 1960's seem to be associated with some rise in employment (fig. 10) but productivity has clearly increased. The peak of employment (over 400 people) was reached in 1929–30. At that time it was between three and four times the present number but production was only a third to a quarter of the present level. Productivity improved at the time of the 1950's production peak. There were

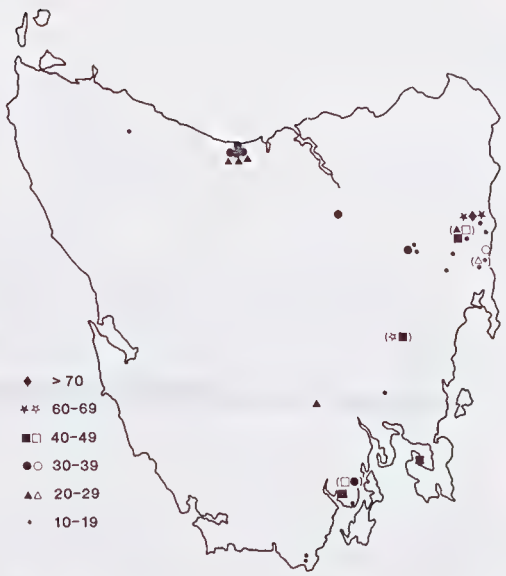


FIG. 8 — Geographical distribution of longevity of Tasmanian coal mines.

fewer "miners" than in the 1930's but production was more than twice as high. This same point was made graphically for the period 1936–56 by Besford (1958: pl. 34), who also commented on the variation in the ratio of imports of NSW coal to Tasmanian coal production (*ibid.*: 139).

In 1858, almost 2700 tonnes of Tasmanian coal was exported, whereas 129 000 tonnes were imported (Booth 1962: appendix B), i.e. a ratio of 48:1 imports to exports. Besford (1958:139) in dealing briefly with the ratio of imported to local coal used, excluded gas and bunker coal on the basis that Tasmanian fields could not produce such coals. With exceptions for short periods only, Tasmanian coals have been used exclusively for steam raising or domestic uses.

Uses of Tasmanian Coal

The quality of Tasmanian coal has controlled the uses to which the coal has been put. The generally low content of volatile carbonaceous matter has usually precluded use in gas making. An exception to this is the Lower Permian coal which was used as a source of town gas for Latrobe (*Cyclopaedia of Tasmania* 2(1900): 239 and Dix (in Jennings 1979: 107)). The Dulverton and Russell Mines

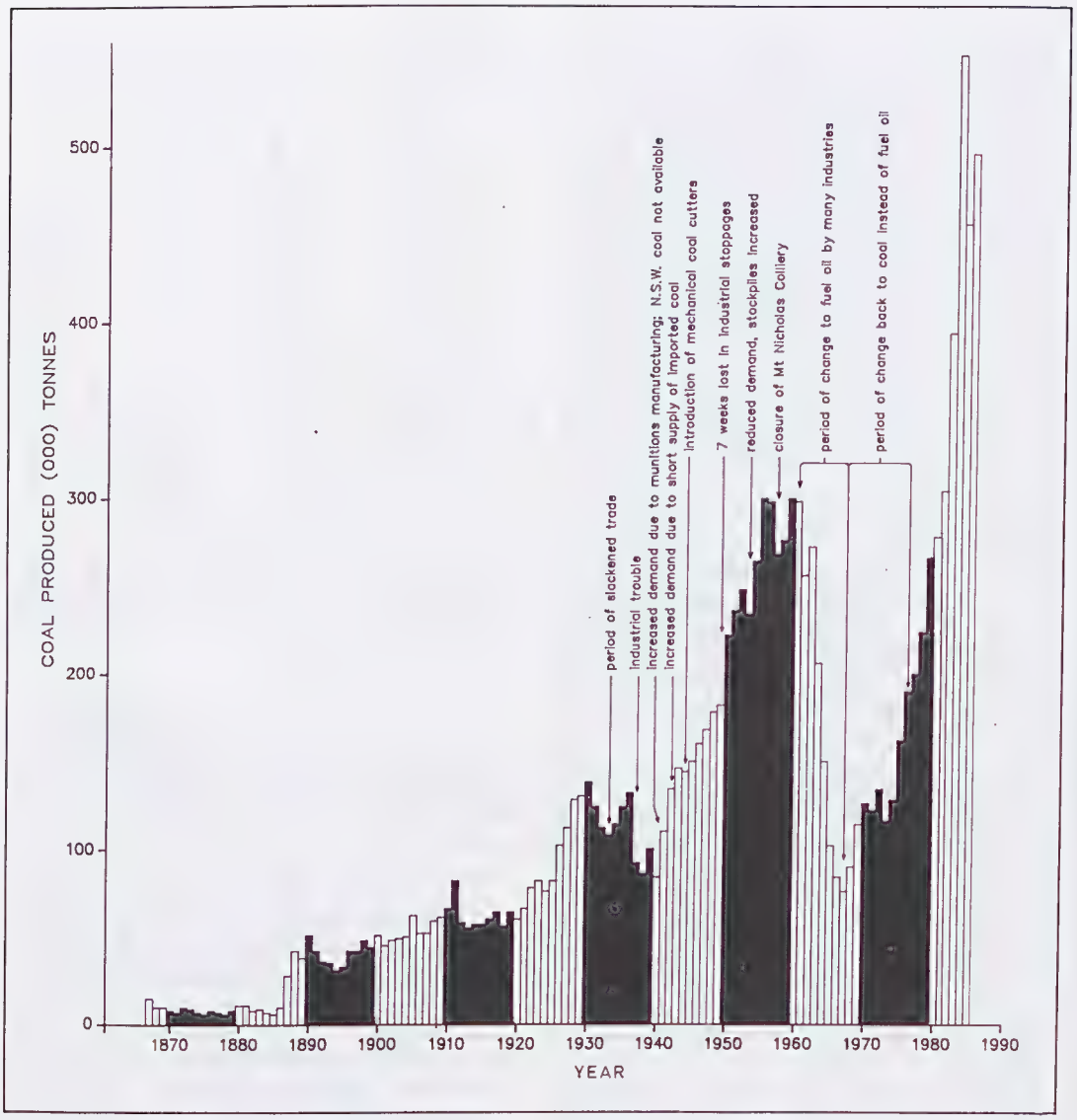


FIG 9 — Production from Tasmanian coal mines from 1865–66 to present; from Department of Mines records.

provided the coal for this. The low content of VM and lack of coking properties has precluded widespread use of the coals for coking and smelting. Some Tasmanian coal was used in smelting in the 1870's (Booth 1962: introduction) but the quantity was small. Only minor quantities of Tasmanian coal have been used for bunkering of ships and there has been some use as locomotive fuel. For both uses the high ash content of the Triassic coals is deleterious and the high sulphur content of the low-ash Lower Permian coals makes the Mersey coals unsuitable for use on the railways.

Last century most of the coal mined locally (and imported) was used as domestic fuel, with minor quantities of the local coal being used by the railways and steamships. During this century local industries, including hop kilns, used increasing amounts of local coal as boiler fuel for steam

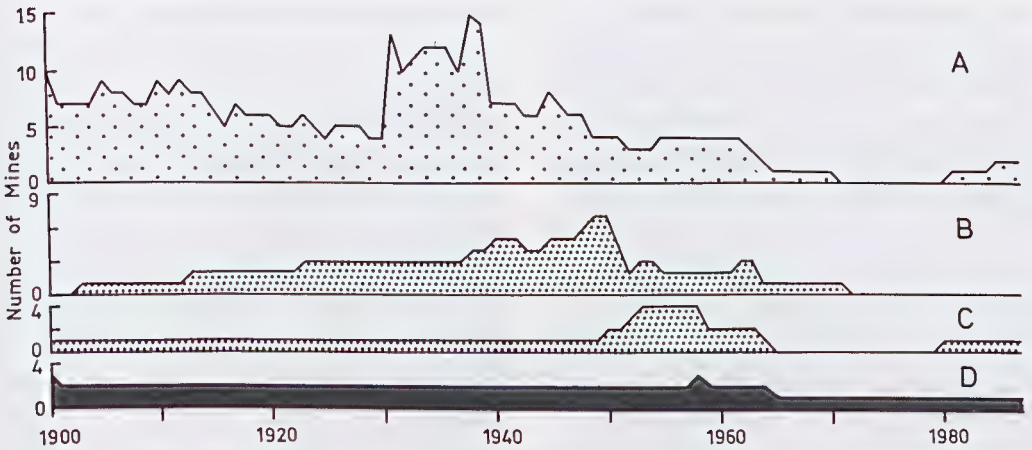


FIG 10 — Number of mines operating in Tasmania annually from 1900 to present, with analysis of size according to number of people directly employed; from Department of Mines records. (A) mines employing 1 to 5 people; (B) mines employing 6–15 people; (C) mines employing 16–50 people; (D) mines employing more than 51 people.

raising or other heating purposes. The railways phased out steam engines in switching to diesel engines from the early 1950's to early 1960's but the drop in consumption by the railways was initially taken up by increased consumption by industry. Through the 1960's, many local industries which had been using coal in increasing quantities as a boiler fuel for steam-raising purposes converted to fuel oil, at the time a cheaper option than coal. One of the main industries using coal prior to this conversion was the paper-making industry (Besford 1958: pl. 33) and this situation continues. Tasmanian coal is now used in a wide variety of secondary industries.

Mine Closures

A summary of the reasons for mine closures is given in appendix 3 and table 4. Early mining ventures were either thwarted by the geological difficulties or lacked sufficient capital to operate with maximum efficiency. A disaster, such as the loading jetty washing away, as happened at Adventure Bay, Seymour and Dalmayne, became a financial hurdle too large to be overcome and the operation closed.

At Catamaran, seven syndicates tried to work the field during the years 1900–40. The early syndicates spent most of their funds on massive infrastructure (which could be seen) such as bins, tramways, etc. and left insufficient funds for mine development proper. The same activity caused the failure of Swift's operation at Seymour and Dr Milligan's Douglas River mining ventures. In the last forty years the prime cause of mine closures has been the loss of markets, due to industry using fuel oil in preference to coal. Even when this trend reversed, the small mines did not re-open. With increased mechanisation and greater tonnages of coal per man produced now than in the days of hand-mining, the opening of a mine has become an expensive operation and can only really be justified on the larger deposits.

TABLE 4

Summary of Reasons For Closure of Tasmanian Coal Mines

	Geological	Mining	Economic	Fortuitous
1850–1900	4 (or 14)	-	2	3
1901–20	-	1	4	1
1921–40	3	2	2+(?)2 or (?)16	1
1941–60	9	1	5	1
1961–80	4	2	3	0
	20 (or 30)	6	16+(?)2 or (?)16	6

One feature of the closures has been the lack of attention to the geology of the coal area before mining began. The thickness and continuities of seams, the presence of faults and of dolerite have not been established prior to commencement of mining and sinking of large amounts of capital in infrastructure. Hills *et al.* (1922: 249–250) warned explicitly of the danger of such lack of attention.

It is significant that, after the rise in the price of oil in the early 1970's, the major thrusts in exploration with a view to almost immediate mine development were by large institutions. The Department of Mines mounted an intensive programme of geological and geophysical work and drilling in northeastern Tasmania from about 1974 to about 1981, with particular intensity from 1979 onward (Director of Mines Reports). Over this period two large companies were exploring in the northeast, one at each of Woodbury, Langloh and Catamaran in Upper Triassic fields and one in the Tertiary at Rosevale. These activities, with the possible exception of those at Woodbury, were in fields where coal had been discovered decades or more than a century ago.

MINING METHODS

The mining methods used in Tasmania are very largely the result of the geological and topographical conditions. Because the seams are almost horizontal (common dip up to 5°) and because the topography in most of the mining areas is rugged, the mine openings are commonly adits. Not infrequently the initial drive is up or down-dip. Water problems have been encountered where the drive is down-dip, e.g. Langloh, Dalmayne (Hills *et al.* 1922: 59). Mines in low-lying areas, e.g. Seymour (Hills *et al.* 1922: 61), Triabunna (*ibid.*: 107), Strathblane (*ibid.*: 151), Catamaran (*ibid.*: 163), New Town (*ibid.*: 173) and on the Mersey field (*ibid.*: 226–228), have been worked from shafts; in a few cases (e.g. Saltwater River) both adits and shafts were used.

Most of the coal mined in Tasmania has been won by the bord-and-pillar method, where parallel headings (bords) are driven and connections made between headings, so creating large blocks of coal (pillars) which are mined on retreat, a method which is often used to work a coal seam which is discontinuous on one horizon due to faulting.

On a number of occasions earlier this century the longwall method was used. This means the coal was mined across one long continuous face, with the roof collapsing behind the advancing face to form the goaf. For this arrangement a block of unfaulted coal is required, a condition not frequently met in most Tasmanian mines. A short or step longwall (where the coal face takes the shape of an irregular curve with blocks of coal left protruding as "steps") was used at the Cornwall Colliery until 1914 and at the Mt Nicholas Colliery in 1925 because of minor faulting. The longwall method was tried at Stanhope in 1943, but collapse of the longwall face in 1944 caused the management to revert to the more suitable bord-and-pillar method. Often miners were brought out from England especially to work in a particular mine, and probably the initial mine design and mode of working was based on their previous experience. Until the mines started to become mechanised (in 1943) mining was done by hand, with pit ponies pulling loaded coal skips to the surface on narrow gauge tram tracks. In 1943 an arc-wall coal cutting machine was installed at the Cornwall Colliery. The neighbouring mines soon also became mechanised, although some hand-mining continued into the 1950's.

The width of present headings (around 5 m) is a legacy from the days of hand-mining, when headings were wide enough for a man to shovel at the side and throw coal into a skip in the middle of the heading (a distance of about seven feet — 2 m). Today the shape of headings and pillars is much more regular than in the old hand-mining days. Fewer headings are required now than when there was a need to have a greater number of working places as there were more steps involved in the process of mining. Holes were bored in the face, charges laid, the face fired, the roof secured, the coal shovelled up. Commonly up to 16 or 20 headings were in use at the one time to provide the mining parties with sufficient working places. Pillars formed by hand-mining were smaller. Opencast mining has been used mainly at Merrywood and occasionally elsewhere, e.g. week-end workings near the old Cardiff Mine, the "Cardiff open-cut" and in front of the main portal at Blackwood West. In most places the overburden-to-coal ratio is too high and the removal of overburden (largely dolerite) would be too expensive to allow this method to be used.

Transport of coal from mine mouth to railhead or jetty was frequently by wooden tramway but at the Cornwall and Mt Nicholas Collieries coal was moved by self-acting ground tramway from mine mouth to screens (Hills *et al.* 1922: 31). At Dalmayne a three-mile (5 km) aerial ropeway was used between the pit and the jetty (Hills *et al.* 1922: 53), and an aerial ropeway 3.6 km long was

used at the Jubilee Colliery, taking coal from the pit top to a railway siding.

CONDITIONS OF MINING

The conditions in which the early miners worked were frequently difficult. Poor ventilation and not enough room to stand upright were common in many mines. The mining of thin seams, even less than two feet (0.60 m) thick in some cases, meant the miners had to work in very cramped conditions.

At Saltwater River convicts were intially employed in the underground mine and conditions were most unpleasant. The mine headings were only 1–2 m high and the ventilation was poor (Ford 1932, Burn 1892). A steam engine was installed in 1842 to raise the coal to the surface. Prior to this the coal was raised up shafts by a winch which used convict labour. Two pumps, which drew water from the workings, also used convict labour. Conditions at the coal mine were described by D. Burn after a visit to the mine in 1842 (see Burn 1892).

> "Next morning I descended the main shaft along with Captain Booth; it is 52 yards [47.5 m] deep. The winch was manned by convicts under punishment. One stroke of the knife might sunder the rope, and then ... however it has never been tried, deeds of ferocity being very infrequent. A gang on the surface worked the main pump and another below worked a horizontal or slightly inclined draw pump which threw water into the chief well ... The seam has been excavated 100 yards [90 m] from the shaft several chambers diverging left and right. The height of the bore is four feet [1.2 m]. The quality of the coal partakes much more of anthracite than of bitumen, it flies a great deal but produces intense heat. The mines are esteemed the most irksome punishment the felon encounters because he labours night and day eight hours on a spell. Continuous stooping and close atmosphere caused our party to be bedewed with perspiration. I cannot therefore wonder at the abhorrence of the compulsory miner in loathing what I conceive to be a dreadful vocation ..."

The Reverend H.P. Fry visited the mine in 1848 and recorded that the shaft was 92.5 m deep, and that 400 convicts were employed at the mine site, although only 83 actually worked underground. Fry (1850) described the workings in detail:

> "...we groped our way with difficulty along passages which were said to be five miles [8 km] in length. The roof in many places was so low that we were obliged to creep along the passage beneath it. The air was so confined that our lamps could with difficulty be kept burning and several of them went out. A few lamps at long intervals were attached to the walls, but seemed only like sparks glimmering in the mist, and not many yards from them the passage was in perfect darkness. There were 83 men at work in the mines when I visited them, the greater number employed in wheeling the coal to the shaft to be hoisted up. They worked without any other clothing than their trousers and perspired profusely. The men in the mine were under the charge of a prisoner-overseer and a prisoner constable."

To be sent to work at the coal mine was regarded as a punishment by the convicts at Port Arthur, although the work at the mines was no more severe than at Port Arthur and the rations were the same (Besford 1957). The punishment rate was, however, high. Hartwell (1954) notes that for the year 1847, 1400 punishments were meted out to the 400 workers. These included 728 sentences of solitary confinement with bread and water, given out by the Superintendent, while the Magistrate imposed 672 punishments of flogging, sentencing to chains, or periods of solitary confinmement.

An *Examiner* published in April 1871, carried a graphic account of the "Don Coal Mines". The adit was only four feet (1.2 m) square and followed the dip of a seam only 0.2 to 0.46 m thick. Drives had been cut along the seam at right angles to the adit and from the drives excavations were made on either side. The miners worked in "recumbent, kneeling or squatting positions." The description is that of a mine working a thin seam by the bord-and-pillar method and with minimum expenditure.

More recently opened mines have more head-room (the seams are thicker in the Triassic coal measures) and mining conditions are more comfortable.

OVERVIEW

The coal-mining industry in Tasmania has not been a major industry but has provided employment directly for up to just over 400 people at a time. It has not been a bigger industry partly for geological reasons. Most of the seams are too thin and the coal

itself is not of high enough quality for export in the face of competition from mines in NSW and Queensland. Gas-making coals are present and have been used as such a little, but the seams of Permian coals with enough vitrinite and or/liptinite to provide gas are thin and very faulted. The Triassic coals, without exception, are inertinite-rich and thus not suitable for gas or coke making; further, they have high ash contents (modally about 20%) and relatively low (modally about 26 mj) specific energies. As noted earlier they have been predominantly used for heating or steam raising.

Despite the difficulties noted above in using Tasmanian coals, and although most mining operations have been short-lived and on a small scale, coal mining has played an important role in the history of at least two communities, that of the Mersey Valley in the 1850's and that of the South Esk Valley after about 1890.

Although settlement had already occurred on the Mersey at Frogmore and elsewhere prior to 1850 (Ramsay 1958), the discovery of coal there and subsequent commencement of mining attracted entrepreneurs, capital and miners to the area (Ramsay 1958: 118–126). Tarleton became "a large town" in the 1850's but by 1870 only one family remained, although there were others at Ballahoo and Sherwood (Ramsay 1958: 127–128). Ramsay (*op. cit.*: 128) noted that "the finding of coal set off the real development of the Mersey estuary", but after the first decade or two other industries replaced coal in importance.

The importance of coal mining to the towns of Avoca, Fingal and St Marys in the South Esk Valley became obvious when Tasmanian companies began to switch from coal-burning to oil-burning furnaces in the 1950's. Dalmayne stopped producing in the early 1950's; five mines — Mt Nicholas, Mt Christie No. 1, Stanhope, Tasmania and Jubilee — stopped producing in the three years beginning 1956 and then a further six stopped in the three years from 1963 (Merrywood, Tasmania [after a reopening], Mt Christie No. 2, Cornwall, The Valley and the Fingal). In all, 14 mines in this one area stopped work in the 18 years beginning 1951. It was reported in 1961 (*Mercury* 20 April) that more than half the 3500 inhabitants of the valley depended directly on coal mining and half of the rest depended on coal for trade and wages. Private and company houses were up for sale but attracted no buyers. The *Mercury* of 15 April 1961 reported that almost sixty miners had lost their jobs over the last two years and over thirty were on forced long-service leave. Within a few months in 1965 (February to April; *Mercury* 17 February, 7 April) it seems that over forty miners lost their jobs out of a mining force of just over 100. Offical figures on employment in the coal-mining industry (Director of Mines Reports for the years 1960 to 1966 inclusive) reveal a loss of 241 jobs in the industry of a total of 307 at the beginning of the period (i.e. 78.5% over seven years or an average of about 11% per annum), with the highest annual loss of 35.2% in 1965. These figures cover the whole industry but few mines were operating outside the Fingal Valley. Many of the miners dismissed were found work with the Forestry Commission working in plantations in the area but the social and economic effects of the closures were severe.

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REFERENCES

Alexander A., 1986: *GLENORCHY, 1804–1964*. Glenorchy City Council, Glenorchy, Tasmania.

Bacon, C.A., 1986a: Brown coal deposits in Tasmania. Unpubl. Rep. Dep. Mines Tasm. 1986/19.

Bacon, C.A., 1986b: Coal in Tasmania. Unpubl. Rep. Dep. Mines Tasm. 1986/43.

Bacon, C.A. & Calver, C.R., 1986: Petrography and palaeoenvironments of some Permian coals, Nicholas Range, north-eastern Tasmania. Unpubl. Rep. Dep. Mines Tasm. 1986/34.

Bacon, C.A. & Everard, J.L., 1981: Triassic rhyolitic ash-fall near Bicheno, Tasmania. *Search* 12(6): 177–8.

Banks, M.R., 1962: Permian. *In* Spry, A.H. and Banks, M.R.(Eds): *THE GEOLOGY OF TASMANIA. J. Geol. Soc. Aust.* 9(2): 189–215.

Banks, M.R., 1971: A Darwin manuscript on Hobart Town. *Pap. Proc. R. Soc. Tasm.* 105: 5–19.

Banks, M.R., 1978: Correlation chart for the Triassic System of Australia. *Bur. Miner. Resour. Geol. & Geophys. Bull.* 156C.

Barlow, N., 1933: *CHARLES DARWIN'S DIARY OF THE VOYAGE OF H.M.S. BEAGLE*. Cambridge University Press.

BESFORD, D., 1958: Coal in Tasmania. *Tech. Rep. Dep. Mines Tasm.* 2: 127–143.

BIGGE, J.T., 1822: *REPORT OF THE COMMISSIONER OF INQUIRY INTO THE STATE OF THE COLONY OF NEW SOUTH WALES*. London.

BLAINEY. G., 1954: Population movements in Tasmania, 1870–1901. *Tasm. Hist. Res. Assoc. Pap. Proc.* 3(4): 62–70.

BLAINEY, G., 1961: Gold and governors. *Hist. Stud. Aust. N.Z.* 9(36): 337–50.

BLAKE, F., 1938: Rooks River Tinfield—Cape Barren Island. Unpubl. Rep. Dep. Mines Tasm. 30–32.

BLAKE, F., 1940: Brown coal and lignite in Tasmania. Unpubl. Rep. Dep. Mines Tasm. 1940: 42–43.

BOOTH, B., 1962: Ninety years of the Tasmanian coal industry. Unpubl. Hons thesis, Univ. Tasm.

BRAND, I., in press: *PENAL COAL*. Jason Publications, Hobart.

BRONGNIART, A., 1807: *TRAITÉ ÉLEMENTAIRE DE MINÉRALOGIE*. Tome 2.

BURN, D., 1892: *AN EXCURSION TO PORT ARTHUR IN 1842*. Facsimile reprint 1972, H.A. Evans & Son, Melbourne.

BURNS, K.L., 1963: Deep drilling near Latrobe. *Tech. Rep. Dep. Mines Tasm.* 7: 29–36.

BURNS, K.L., 1964: Devonport. *Geological Atlas 1 mile ser. Explan Rep.* K/55-6-29. Tasm. Dep. Mines.

CALVER, C.R., CLARKE, M.J. & TRUSWELL, E.M., 1984: The stratigraphy of the Late Palaeozoic borehole section at Douglas River, eastern Tasmania: a synthesis of marine macro-invertebrate and palynological data. *Pap. Proc. R. Soc. Tasm.* 118: 137–161.

CANTRILL, T.C., 1914: *COAL MINING*. Cambridge University Press, London.

CAREY, S.W., 1946: Report on peat, lignite and brown coal deposits on King Island. Unpubl. Rep. Dep. Mines Tasm. 1946: 6–29.

CLARKE, W.B., 1878: Remarks on the sedimentary formations of New South Wales. Government Printer, Sydney.

COOKSON, I.C., 1953: The identification of the Sporomorph *Phyllocladidites* with *Dacrydium* and its distribution in southern Tertiary deposits. *Aust. J. Bot.* 1: 474.

COOKSON, I.C., 1954a: Some Dicotyledonous pollen types from Cainozoic deposits in the Australian Region. *Aust. J. Bot.* 2: 197–219.

COOKSON, I.C., 1954b: The Cainozoic occurrence of Acacia in Australia. *Aust. J. Bot.* 2: 52.

COOKSON, I.C., 1956: Pollen grains of the Ephedra type in Australian Tertiary deposits. *Nature* 177: 47.

COOKSON, I.C., 1957: On some Australian Tertiary spores and pollen grains that extend the geological and geographical distribution of living genera. *Proc. R. Soc. Vict.* 69: 41–53.

COOKSON, I.C., 1967: Some Early Tertiary microplankton and pollen grains from a deposit near Strahan, western Tasmania. *Proc. R. Soc. Vict.* 80(1): 131–140.

COOKSON, I.C. & DUIGAN, S., 1951: Tertiary Araucariaceae from South-Eastern Australia with notes on living species. *Aust. J. Sci.* B4: 415–449.

COOKSON, I.C. & PIKE, K., 1953: A contribution to the Tertiary occurrence of the genus *Dacrydium* in the Australian Region. *Aust. J. Bot.* 1: 474.

CRAPP, C.E. & NOLAN, R.C., 1975: Newcastle district. *In* Traves, D.M. & King, D.(Eds): *ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA. 2 — COAL*. A.I.M.M. Monograph Series 6, Parkville, Victoria: 163–175.

DAINTREE, R., 1872: Notes on the geology of Queensland. *Q. J. Geol. Soc. Lond.* 28: 271–317.

DE LA BECHE, H.T., 1851: Analysis of coal from Van Diemens Land with Report. *Pap. Proc. R. Soc. V.D.L.* I: 265–266.

DENISON, W., 1870: *VARIETIES OF VICE REGAL LIFE*. Longman Green and Co., London.

DETTMAN, M., 1961: Lower Mesozoic megaspores from Tasmania and South Australia. *Micropaleontology* 7: 71–86.

DICKINSON, D.R., 1945: Ben Lomond Coal. Unpubl. Rep. Dep. Mines Tasm.: 12– 13.

DULHUNTY, J.A. & DULHUNTY, R., 1949: Notes on microspore types in Tasmanian Permian Coals. *Proc. Linn. Soc. N.S.W.* 74(3–4): 132–139.

DUNN, E.J., 1910: Biographical sketch of the founders of the Geological Survey of Victoria. *Bull. Geol. Surv. Vict.* 23.

ELFORD, H.S. & MCKEOWN, M.R., 1947: *COAL MINING IN AUSTRALIA*. Tait, Melbourne.

FENTON, J., 1891: *BUSH LIFE IN TASMANIA FIFTY YEARS AGO*. Hazell, Watson & Viney, London and Aylesbury.

FORD, T.G., 1932: *INHUMANITY. HISTORICAL TALES OF OLD CONVICT DAYS ... AND OTHER STORIES BY THE CAPTAIN*. J. Walch, Hobart.

FORSYTH, S.M., 1984: Oatlands. *Geological Atlas 1:50,000 ser. Explan. Rep.* Sheet 68 (8313S). Tasm. Dep. Mines.

FRY, H.P., 1850: *A SYSTEM OF PENAL DISCIPLINE WITH A REPORT ON THE TREATMENT OF PRISONERS IN GREAT BRITAIN AND IN VAN DIEMENS LAND*. Longman, Green and Longman, London.

GILL, E.D. & BANKS, M.R., 1956: Cainozoic history of the Mowbray Swamp and other areas of north-western Tasmania. *Rec. Q. Vict. Mus.* 6: 1–41.

GOULD, C., 1861a: Coalfields (Fingal and East Coast). Report of Government Geologist. *House of Assembly Pap. Tasm.* 1861(9).

GOULD, C., 1861b: Mersey Coalfield. *House of Assembly Pap. Tasm.* 1861(9).

GOULD, C., 1861c: Report on ascertaining the commercial value of coal. *House of Assembly J. Tasm.* 65.

GOULD, C., 1865: Notes on the geological structure of the north-east coast of Tasmania. *Pap. Proc. R. Soc. Tasm.* 63–66.

GOULD, C., 1869: Coal south of Oatlands. *House of Assembly Pap. Tasm.* 1869(18).

HALE, G.E.A., 1962: Triassic System. *In* Spry, A.H. & Banks, M.R. (Eds): *THE GEOLOGY OF TASMANIA*. *J. Geol. Soc. Aust.* 9(2): 217–231.

HARRIS, W.K., 1968: Tasmanian Tertiary and Quaternary microfloras. Summary Report. *Dep. of Mines S. Aust. Pal. Rep.* 5/68.

HARTWELL, R.M., 1954: *ECONOMIC DEVELOPMENT OF VAN DIEMENS LAND, 1820–1850.* Melbourne University Press, Melbourne.

HEARD, D., 1981: *THE JOURNAL OF CHARLES O'HARA BOOTH.* Tasmanian Historical Research Association, Hobart.

H.E.C. (HYDRO-ELECTRIC COMMISSION), 1967: Tasmanian coal resources investigation, Fingal area — geological report. H.E.C., Hobart.

HILLS, L., REID, A.M., NYE, P.B., KEID, H.G.W. & REID, W.D., 1922: The Coal Resources of Tasmania. *Geol. Surv. Tasm. Miner. Resour.* 7.

HOBBS, J., 1824: Boat expeditions around Tasmania, 1815–1816 and 1824. *House of Assembly Pap. Tasm.* 1881. (Reprinted 1986): *THE LOG.* Government Printer, Hobart.

HODDINOTT, W.G., 1967: Joseph Milligan (1807–1884). *In* Pike D., (Ed.): *AUSTRALIAN DICTIONARY OF BIOGRAPHY. Vol. 2.* Melbourne University Press, Melbourne: 230–231.

HORNE, T., 1864: Report of the Select Committee on Coalfields, 1864. *House of Assembly Pap. Tasm.* 1864 (95).

HUGHES, T.D., 1952: Coal near Mt Lloyd. Unpubl. Rep. Dep. Mines Tasm. 1952: 17–19.

HUGHES, T.D., 1955: Notes on coal prospects near Dover. Unpubl. Rep. Dep. Mines Tasm. 1955: 30–31.

HUGHES, T.D., 1960: Thermal springs, Hastings. *Tech. Rep. Dep. Mines Tasm.* 5: 44–46.

HUGHES, T.D., 1962: Coal at West Takone. *Tech. Rep. Dep. Mines Tasm.* 6: 55–57.

HUGHES, T.D. & BURNS, K.L., 1961: Notes on the geology of the proposed factory site for A.P.P.M. at Wesley Vale. *Tech. Rep. Dep. Mines Tasm.* 5: 198–203.

HUNT, J.W., 1987: Sulphur in the Permian coals of eastern Australia: variation and geological control. *Aust. Coal Geol.* 7: 11–32.

JAMESON, R., 1808: *ELEMENTS OF GEOGNOSY. VOL. 3. SYSTEM OF MINERALOGY.* Blackwood, Edinburgh.

JENNINGS, I.B., 1979: Sheffield. *Geological atlas 1 mile ser. Explan. Rep.* Sheet 37 (8115S). Tasm. Dep. Mines.

JOHNSTON, R.M., 1873: Regarding the composition and extent of certain Tertiary beds in an around Launceston. *Pap. Proc. R. Soc. Tasm.*: 39–47.

JOHNSTON, R.M., 1875: The Launceston Tertiary basin — second paper. *Pap. Proc. R. Soc. Tasm.*(1874): 53–62.

JOHNSTON, R.M., 1887: Fresh contributions to our knowledge of the plants of Mesozoic age in Tasmania. *Pap. Proc. R. Soc. Tasm.* (1886): 160–182.

JOHNSTON, R.M., 1888: *A SYSTEMATIC ACCOUNT OF THE GEOLOGY OF TASMANIA.* Government Printer, Hobart.

JOHNSTON, R.M., 1892: Notes on a collection of plant impressions from the Henty River. *Pap. Proc. R. Soc. Tasm.* (1891): 11–13.

JOHNSTON, R.M., 1894: Further contributions to the fossil flora of Tasmania. Part 1. *Pap. Proc. R. Soc. Tasm.* (1893): 170–178.

JOHNSTON, R.M., 1901: Progress of Tasmania 1816 to 1900. Tasm. Secy Mines Rep. (1900–01).

JULEN, H., 1976: *THE PENAL SETTLEMENT OF MACQUARIE HARBOUR 1822–1833: AN OUTLINE OF ITS HISTORY.* Mary Fisher Bookshop, Launceston.

KEID, H.G.W., 1952: The Strathblane, Ida Bay and Catamaran Coalfields. Unpubl. Rep. Dep. Mines. Tasm.: 25–29.

KRAUSE, F., 1884: Report on the New Town coal deposits. *House of Assembly Pap. Tasm.* 1884(59).

LABILLARDIÈRE, J.-J.H. DE, 1800: *VOYAGE IN SEARCH OF LA PÉROUSE DURING THE YEARS 1791–1794.* Stockdale, London.

LEWIS, A.N. & VOISEY, A., 1938: A record of volcanic activity in Tasmania during Triassic times. *Pap. Proc. R. Soc. Tasm.* (1937): 31–39.

L'HUILLIER, L., 1969: Depression and a national economy. *In* Griffin, J.(Ed.): *ESSAYS IN ECONOMIC HISTORY OF AUSTRALIA.* Jacaranda Press, Brisbane:186–206.

MACCULLOCH, J., 1831: *A SYSTEM OF GEOLOGY WITH A THEORY OF THE EARTH.* Longman, London.

MACKANESS, G.(Ed.), 1947: *SOME PRIVATE CORRESPONDENCE OF SIR JOHN AND LADY JANE FRANKLIN (TASMANIA, 1837–1845).* Ford, Dubbo, N.S.W.

MAUDE, A.M., 1965: Discovery and exploration. *In* Davies, J.L.(Ed.): *ATLAS OF TASMANIA.* Lands and Surveys Dep., Hobart: 38–39.

MCGHEE, R., 1969: The long boom, 1860–1890. *In* Griffin, J.(Ed.): *ESSAYS IN ECONOMIC HISTORY OF AUSTRALIA.* Jacaranda Press, Brisbane: 135–185.

MCKAY, A., 1962: *JOURNALS OF THE LAND COMMISSIONERS FOR VAN DIEMENS LAND 1826–1828.* Univ. Tasm.–Tas.Hist.Res.Assoc.

M'COY, F., 1847: On the fossil botany and zoology of the rocks associated with the coal of Australia. *Ann. Mag. Nat. Hist.* 20: 145–7, 226–236, 298–312.

M'COY, F., 1848: On the plants of the New South Wales and Van Diemens Land Coal fields. *B.A.A.S. Rep.* (1847): 64–65.

MCNEIL, R.D., 1961: Geological reconnaissance of the Arthur River area. *Tech. Rep. Dep. Mines Tasm.* 5: 46–60.

MILLIGAN, J., 1849: Reports on the coal basins of Van Diemens Land. *Pap. Proc. R. Soc. V.D.L.* I:1–82; read Aug. 1848 to Feb. 1849.

MILLIGAN, J., 1852: Report on the coal said to have been found at the Don River, and upon the west bank of the Tamar River in Tasmania. *Pap. Proc. R. Soc. Tasm.* 2: 90–106; read July 1851.

MONTGOMERY, A., 1891: Report on the proposal to bore for coal in the township of Triabunna, Spring Bay, and its neighbourhood. *Tasm. Secy Mines Rep.* 1890–1891: 15–22.

MONTGOMERY, A, 1892: Report on the Ben Lomond district. *Tasm. Secy Mines Rep.* 1891–2: 25–40.

MONTGOMERY, A., 1893: Report on the country between Mole Creek and the Mt Dundas Silver Field and on the discovery of coal at Barn Bluff. *Tasm. Secy Mines Rep.* 1892–3.

MONTGOMERY, A., 1894: Report on the Lawrenny–Langloh Coalfield. *Tasm. Secy Mines Rep.* 1893–4: xli–l.

MONTGOMERY, A, 1896: Report on the mineral fields of the Gawler River, Penguin, Dial Range, Mount Housetop, Table Cape, Cam River and portion of the Arthur River district. *Tasm. Secy Mines Rep.* 1895–6: i–xx.

MORRISON, K.C. & BACON, C.A., 1986: Comparison between the Fingal and Langloh Coalfields, Tasmania Basin. *Coal Geol.* 6: 41–57.

MURRAY, C.G., 1983: Permian geology of Queensland. Keynote address. In *PERMIAN GEOLOGY OF QUEENSLAND*. Geol. Soc. Aust. Qld Div., Brisbane: 1–32.

NYE, P.B., 1923: The silver-lead deposits of the Waratah district. *Bull. Geol. Surv. Tasm.* 33.

NYE, P.B., 1928: Report on the borehole at Northdown. Unpubl. Rep. Dep. Mines Tasm.

NYE, P.B., 1929: Departmental report on coal at Harland Rise, Evandale. Unpubl. Rep. Dep. Mines Tasm. 1929: 24.

NYE, P.B. & BLAKE, F., 1938: Geology and Mineral Deposits of Tasmania. *Bull. Geol. Surv. Tasm.* 44.

NYE, P.B., FINUCANE, K.J. & BLAKE, F., 1934: The Smithton district. *Bull. Geol. Surv. Tasm.* 41.

PLAYFORD, G., 1965: Plant microfossils from Triassic sediments near Poatina, Tasmania. *J. Geol. Soc. Aust.* 12(1): 173–210.

PLOMLEY, N.J.B., 1971: Friendly Mission: The Tasmanian Journals and Papers of G.A. Robinson 1829–1834, a supplement. *Tasm. Hist. Res. Assoc. Pap. Proc.* 18(1): 7–32.

PRETYMAN, E.R., 1967: Kelly, James (1791–1859). *In* Pike, D. (Ed.): *AUSTRALIAN DICTIONARY OF BIOGRAPHY* 2: 36–37.

RAMSAY, C., 1958: *WITH THE PIONEERS*. Mercury, Hobart.

REID, A.M., 1919: The Mount Pelion Mineral Deposit. *Bull. Geol. Surv. Tasm.* 30.

REID, A.M., 1924: The oil shale resources of Tasmania. *Miner. Resour. Tasm.* 8(1).

RUDE, G., 1967: Zephaniah Williams. *In* Pike, D. (Ed.): *AUSTRALIAN DICTIONARY OF BIOGRAPHY* 2: 601–602.

SCOTT, P., 1965: Land settlement. *In* Davies, J.L. (Ed.): *ATLAS OF TASMANIA*. Lands and Surveys Dep., Hobart: 43–45.

SCOTT, T.H., 1824: Sketch on the geology of New South Wales and Van Diemens Land. *Ann. Philos.* June 24: 461–462.

SELWYN, A.R.C., 1855: Report on the geological relations of some of the coal seams of Van Diemens Land, their probable extent and relative economic value. *Pap. Proc. R. Soc. V.D.L.* III(1): 116–141.

SHAW, A.G.L. & BRUNS, G.R., 1947: *THE AUSTRALIAN COAL INDUSTRY*. Melbourne University Press.

SMYTH, M., 1979: Petrology of the Duncan Seam from Duncan Mine, Fingal, Tasmania. CSIRO Fuel Science Unit Rep.

SMYTH, M., 1980: Coal encounters of the third kind: Triassic. *Coal Geol.* 2(3–4): 161–178.

SPROD, T.D., 1977: *ALEXANDER PEARCE OF MACQUARIE HARBOUR. CONVICT-BUSHRANGER-CANNIBAL*. Cat and Fiddle Press, Hobart.

STRACHEY, J., 1719: A curious description of the strata observed in the coal-mines of Mendip in Somersetshire: *Phil. Trans. R. Soc.* 30: 968–973.

STRZELECKI, P.E. VON, 1842: On certain varieties of Australian coal. *Tasm. J. Nat. Sci.* 1(3): 190–203.

STRZELECKI, P.E. VON, 1845: *PHYSICAL DESCRIPTION OF NEW SOUTH WALES AND VAN DIEMENS LAND*. Longman, Brown, Green and Longmans, London.

TASMANIAN YEAR BOOK No. 9: 1975. ABS Tasm. Office, Government Printer, Hobart.

THREADER, V.M., 1972: Diamond drilling at the Sandfly Coal Mine, Kaoota. *Tech. Rep. Dep. Mines Tasm.* 15: 40–43.

THUREAU, G., 1881a: Report on the southern coal measures at Sandfly, Parish of Longley, County of Buckingham. *House of Assembly Pap. Tasm.* 1881(109): 12–14.

THUREAU, G., 1881b: Report on the coal mines in the vicinity of Gardner's and Randall's Bays. *House of Assembly Pap. Tasm.* 1881(109).

THUREAU, G., 1883c: The Carboniferous deposits near New Town. *House of Assembly Pap. Tasm.* 1883(3).

TOWNROW, J.A., 1962: Palaeontology; Depositional Environments. *In* Spry, A.H. & Banks, M.R. (Eds): *THE GEOLOGY OF TASMANIA. J. Geol. Soc. Aust.* 9(2): 224–225, 230.

TOWNROW, J.A., 1964: A speculation on the Rhaeto-Liassic climate of Tasmania. *Pap. Proc. R. Soc. Tasm.* 98: 113–118.

TRUSWELL, E.M., 1978: Palynology of the Permo-Carboniferous in Tasmania, and interim report. *Bull. Geol. Surv. Tasm.* 56.

TWELVETREES, W.H., 1901: Report on the mineral districts of Zeehan and neighbourhood. Eden Coal Mine. *Tasm. Secy Mines Rep.* (1900–01): 105–106.

TWELVETREES, W.H., 1902a: Outlines of the geology of Tasmania. *Pap. Proc. R. Soc. Tasm.* (1900–01): 58–74.

TWELVETREES, W.H., 1902b: Report on country on the east shore of Lake Sorell, and on a discovery of coal near Oatlands. *Tasm. Secy Mines Rep.* 1901–02: 159–169.

TWELVETREES, W.H., 1902c: Report on the occurrence of coal near Catamaran River, Recherche Bay. *Tasm. Secy. Mines Rep.* 1901–02: 132–138.

TWELVETREES, W.H., 1903: Report on kerosene shale and coal seams in the Parish of Preolenna. *Tasm. Dep. Mines Rep., Old Series* 206.

TWELVETREES, W.H., 1904: Report on coal near George Town and slate near Badger Head. *Tasm. Dep. Mines Rep., Old Series* 228.

TWELVETREES, W.H., 1906: On coal at Mt Rex. *Tasm. Secy. Mines Rep.* 1905: 1–8.

TWELVETREES, W.H., 1911: The tasmanite shale fields of the Mersey District. *Bull. Geol. Surv. Tasm.* 11.

TWELVETREES, W.H., 1915: The Catamaran and Strathblane coal fields, and coal and limestone at Ida Bay (southern Tasmania). *Bull. Geol. Surv. Tasm.* 20.

VALLANCE, T.G., 1981: The fuss about coal-troubled relations between palaeobotany and geology. *In* Carr, D.J. and Carr, S.G.M. (Eds): *PLANTS AND MAN IN AUSTRALIA*. Academic Press, Sydney: 136–176.

WALKOM, A.B., 1925: Notes on some Tasmanian Mesozoic Plants. Part I. *Pap. Proc. R. Soc. Tasm.* (1924): 73–89.

WALKOM, A.B., 1926: Notes on some Tasmanian Mesozoic Plants. Part II. *Pap. Proc. R. Soc. Tasm.* (1925): 63–74.

WALLER, G.A., 1902: Report on the recent discovery of cannel coal in the Parish of Preolenna, and upon the New Victory Copper Mine near the Arthur River. *Tasm. Secy Mines Rep.* 1901–02: 77–90.

WARD, C.R., 1984: *COAL GEOLOGY AND TECHNOLOGY*. Blackwell Scientific, Melbourne.

WHITHAM, L.S., 1973: The Sandfly coal mine and tramway. *Tasm. Hist. Res. Assoc. Pap. Proc.* 20: 201–209.

WHITHAM, L.S., 1983: The Catamaran colliery and its transport systems. *Tasm. Hist. Res. Assoc. Pap. Proc.* 30(2): 69–81.

WILSON, R.G., 1975: Southern Coal-field. *In* Traves, D.M. & King, D. (Eds): ECONOMIC *GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA — 2. COAL*. A.I.M.M. Monograph Series 6, Parkville, Victoria: 206–218.

WINCH, N.J., 1823: An account of some specimens of rocks etc. from Van Diemens Land and N.S.W. *Thomson's Annals Phil. n.s.* V: 341–342.

ZITTEL, K.A. VON, 1901: *HISTORY OF GEOLOGY AND PALAEONTOLOGY TO THE END OF THE NINETEENTH CENTURY*. Walter Scott, London.

ABBREVIATIONS USED FOR CITATIONS IN TEXT

Records Held in Tasmanian State Archives

CGF — Comptroller General's File.
CON — Convict files, State Archives.
CSD — Records of Chief Secretary's Department.
CSO — Records of Colonial Secretary's Office.
GO — Governor's Office records.
HRA — Historical Records of Australia.
HRNSW — Historical Records of New South Wales.
LSD — Records of Lands and Surveys Department.

Other

DoM — Department of Mines
HAJ — House of Assembly Journals
TSA — Tasmanian State Archives
VDL — Van Diemens Land

(accepted 12 May 1989)

APPENDIX 1

Discoveries and Discoverers of Coal in Tasmania

In preparing this appendix an attempt has been made to determine as closely as possible the date of discovery. In very few cases can dates be quoted. In more cases a year, with or without month, can be determined. Much more commonly it has been possible only to quote the date of the earliest public record of a discovery. In such cases the year of the record is preceded by a "<"; thus "<1833" indicates that the discovery was made in or prior to 1833. In a few cases the site of a discovery can be determined accurately from old maps and the sites identified on modern, detailed maps. Such sites are given the appropriate grid co-ordinates e.g. DM970908, as determined from the Tasmanian 1:100 000 topographic maps. All points in Tasmania lie in Universal Grid Zone 55G. In some cases sites of discovery can only be approximated: in such cases the co-ordinates are bracketed. The geological position of the coal discovered is indicated by the letters "LP" (Lower Permian), "UP" (Upper Permian), "UTr" (Upper Triassic) and "L" for lignite of Tertiary age, the older coals being black coals. Not all discovery sites are listed by number; thus only the first discovery within the one geological structure is numbered. Even so, there are many discoveries listed because the coal measures are much broken by faulting and dolerite intrusion. Wherever possible the name (and occupation) of the discoverer(s) are noted and a reference given to the first public record of the discovery. * following the name of the discoverer indicates a reward lease granted; † a reward lease applied for, not granted.

Item	Date	Locality	Age	Discoverer	Reference
1	15.2.1793	South Cape Bay DM850730	Tr	J-J.H. de Labillardière (Explorer)	Labillardière 1800, 2: 22
2	8.11.1803	Coal River, Richmond EN36656790	Tr	James Meehan (Surveyor)	TSA Map, Monmouth Plan 0
3	1804	Tamar River, western shore 2 miles (3 km), above Middle Island just north of Blackwood Hills (DQ909438)	L	Anon.	Paterson HRNSW V: 500 ("bituminous earth")
4	1809	Schouten Island (FP030160)	Tr	James Stacey (Sailor, shipwrecked)	GO 39/4: 29
5	?1813 (certainly pre-1823)	Jerusalem (Colebrook) (EP294945)	Tr	Anon.	Map engraved by Chas Thompson, Edinburgh, from survey by Capt. Dixon, *Skelton of Whitby*. Dixon was in Hobart in 1823 (Besford 1958).
6	1815	Macquarie Harbour (Coal Head) (CP705140)	L	Capt. James Kelly (mariner and exporer)	*Hobart Town Gazette* 15 June 1876
7	<6.3.1820	Adventure Bay EN261018	UP	Thomas Kent (tanner)	HRA III(3): 257
8	<1823	New Town (EN245545)	Tr	Anon.	Winch 1823 (based on specimens sent by J. Scott)
9	1824	Huon Inlet (?Coal Mine Bay — now Sandrock Bay) (EN079126)	UP	Thomas Scott	Leg. Counc. J. 6, pap.16, 1861
10	<1831	New Norfolk	?Tr	Anon.	*Ross's Almanack* 1831: 30
11	<1831	Jericho (?Sag Hill) (EN039974)	Tr	Anon.	*Ross's Almanack* 1831: 30
	<1831	Satellite Island — incorrect — there is no coal on this island			*Ross's Almanack* 1831: 30

Item	Date	Locality	Age	Discoverer	Reference
12	1832	Near Hampshire (?West Takone CQ718412, ?Preolenna ~CQ760440)	LP	Joseph Milligan (surgeon and part-time geologist)	*VDL Co. Ann. Rep.* 1832
13	<May 1833	Plunkett Point EN586402	Tr	George Woodward & James Hughes (surveyors)	CSO 1/680/15052; GO33/16, 265–5; O'Hara Booth J. 23 May 1833 (Heard 1981)
14	1833	Coal Bluff, Prices (=Halfway) Bay (EN606358)	Tr		O'Hara Booth letter 15.10.1833, TSA
15	Feb 1834	New Signal Hill (Mt Communication) (EN552322)	Tr		Heard 1981: 169
14A	1837 (2nd rep.)	Deer Point	Tr		Llotsky CSO 5/72/1584
16	<Jul 1838	Five Mile Beach	Tr?	Anon.	O'Hara Booth J. (Heard 1981: 226)
17	Dec 1838	Recherche Bay (northern part) (DM928802)	Tr	Capt. King (mariner)	Mackaness 1947; n.b. Strzelecki 1845: 137, wrote of two shafts at Recherche Bay
18	<1840	Southport (DM970908)	UP 1840	Anon.	*Exec. Counc. Min.* 19 May
5A	27.7.1841 (redisc.)	Jerusalem (Colebrook)	Tr	James Clare	LSD I-28-458; 1 Aug 1841
19	<Mar 1843	Apsley River (Llandaff) (FP006584)	Tr	Jesse & Isaac Garland (ticket-of-leave convicts: "in the mining business")	CSO 22/84/1807
20	<Mar 1843	Denison Rivt (FP011687)	Tr	Jesse & Isaac Garland	CSO 22/84/1807
21	1843 (certainly <1849)	Douglas River (FP002743)	Tr	Anon.	J. Lyne, Apslawn in *Proc. R. Soc. V.D.L.* 1: 163
22	<1845 (prob. 1840–42)	Nine Mile Marsh	L	Anon.	Strzelecki 1845: 139
23	<1845 (prob. 1840–42)	Spring Hill (London Inn) EP212023	Tr	Anon.	Strzelecki 1845: 128
24	<1845 (prob. 1840–42)	Ben Lomond (southern side)	Tr	Anon.	Strzelecki 1845: 126
25	<1845 (prob. 1840–42)	South Esk Valley	L	Anon.	Strzelecki 1845: 135

Item	Date	Locality	Age	Discoverer	Reference
26	<29.7.1848	Falmouth (possibly near Germantown) (EQ988012)	LP	Anon.	*Hobart Town Courier*
27	<Nov 1848	"Lynwood", south of Colebrook (EN338848)	Tr	Blinkworth	Milligan 1849: 73
28	Nov 1848	Fingal (EP840895)	Tr	Anon.	Milligan 1849: 47
29	<Nov 1848	Mt Nicholas (EP925984)	Tr	Anon.	Milligan 1849: 50
30	<Dec 1848	Spring Bay EN758945	Tr	Capt.(?) Vicary	*Proc. R. Soc. VDL* I: 159
31	<1849	Langloh ("High Plains") DN843904	Tr	Chilton	*Proc. R. Soc. VDL* I: 173
32	<1849	Back River, Buckland EN64259045	Tr	Anon.	*Proc. R. Soc. VDL* I: 175
20A	<1849 (?redisc.)	Lagoon Rivt (=Denison River) about 5 miles (8 km) from Wabbs Hbr (=Bicheno)	Tr	Anon.	*Proc. R. Soc. VDL* I: 175
33	<13.3.1849	Ouse River DN76059635	L	Anon.	*Proc. R. Soc. VDL* I: 272
34	<8.5.1850	Beckfords, Tamar River	L	Anon.	*Proc. R. Soc. VDL* I: 278
35	Jul 1850	Ben Lomond Rivt EP482857	Tr	J. Scott (Surveyor)	Letter J. Scott to J. Milligan 21.3.1854. R. Soc. Tasm. Archives, Secretary's correspondence
36	<13.11.1850	Three Hut Point, Gordon (EN194096)	UP	Anon.	*Proc. R. Soc. VDL* I: 298
37 DQ431313	<12.3.1851	Don River, Bott Gorge	LP	Powell & Ayres, timber spliters	*Proc. R. Soc. VDL* II(1): 141–142; Fenton 1891: 259
3A (redisc.)	<14.5.1851	Blackwood Hills — well sunk in flat on west bank of Tamar River, 2–3 miles (~4 km) below Point Rapid (Rowella) (DQ909438)		Ralston	*Proc. R. Soc. VDL* II(1): 146
38	1851 (early)	Kelso (DQ820500)	L	? J. Fereday (rector)	*Proc. R. Soc. VDL* II(1): 148
39	<18.5.1851	?Port Sorell, in well at 28.6 m	?L		Anon.*Proc. R. Soc. VDL* II(1): 146; forwarded by Mr J.A. Wheeler of Port Sorell
40	< Dec 1851 (may be redisc. of 24 or 35)	Ben Lomond (3500 ft ~1100 m) (EP594930)	Tr	?J. Milligan (surgeon and acting geologist)	*Proc. R. Soc. VDL* II(1): 166
35A	<13.8.1851 (redisc.)	"Kingston" (near Avoca)		?Cotton	*Proc. R. Soc. VDL* II(1): 153

Item	Date	Locality	Age	Discoverer	Reference
41	<Dec 1851	St Pauls River (S side of)	Tr	J. Milligan (surgeon and acting geologist)	*Proc. R. Soc. VDL* II(1): 167
42	<1852	Whirlpool Reach (DQ924370)	L	Reid	*Proc. R. Soc. VDL* II(1): 104
43	1852 (late)	Coal Hill (near Mt Byron) DP191492	UP	G.W. Burgess (contract surveyor)	*Hobart Town Courier* 7 June 1853
44	<May 1853	"Bryn Estyn" estate, New Norfolk (near EN004640)	?Tr	Anon.	*Proc. R. Soc. VDL* II(1): 488
45	<Mar 1854	Freshwater Point (EQ064230)	L	?P.S. Tomlins	*Proc. R. Soc. VDL* III(1): 161
9A	<Aug 1854 (?redisc.)	Huon Rover (left bank near Surveyors Beach; possibly Sandrock Bay)	UP	?J.L. Maclaine	*Proc. R. Soc. VDL* III(1): 183
46	<Nov 1854	Top of Constitution Hill, Dysart EN186859	Tr	?T. Flude	*Proc. R. Soc. VDL* III(1): 192
47	<1855	Russell DQ454342	LP	Z. Williams (miner)	*Proc. R. Soc. VDL* (1855): 136; Burns 1964: 226
48	1855	Denny Gorge DQ431338	LP	Anon.	Gould 1861b; Burns 1964: 222
49	1855 DQ472334	Denison, Tarleton	LP	Anon.	Selwyn 1855; Burns 1964: 226
50	1855	Plenty (DN980680)	Tr	A.R.C. Selwyn (geologist)	*Pap. Proc. R. Soc. Tasm.* 1855: 116
32A	1855 (redisc.)	Back River, Prossers Plains	Tr	A.R.C. Selwyn (geologist)	*Pap. Proc. R. Soc. Tasm.* 1855: 123
51	1855	Tarleton DQ472334	LP	Z. Williams (miner)	Burns 1964: 226
52	<1856	"Sherwood", Clyde River (doubtful record)		?Sherwin	*Rep. R. Soc. VDL* 1856: 34
53	<1856	Nook (Rays Prospect) DQ436291	LP	Anon.	*DoM Coal Production Records*
54	<1857	Detention River (mouth of) (CQ690740)	L	?Emmett	*Rep. R. Soc. V.D.L.* 1857: 34
55	<1857	Don DQ445347	LP	Anon.	Twelvetrees 1911: Burns 1964: 226
56	<1858	Alfred DQ493333	LP	Anon.	Burns 1964: 226
57	1861	Seymour (FP066764)	Tr	Algernon H. Swift (mining & civil eng.)	*CSD* 4/6/40, 11 Dec 1861; Horne, T. Report of Select Committee on Coalfields. House of Assembly Pap. 95, 1864: 20

Item	Date	Locality	Age	Discoverer	Reference
58	1861	Dalmayne (FP035845)	Tr	Charles Gould (geologist)	Gould 1861a
41A	1862 (?redisc.)	Lewis Hill (EP790675)		Z. Williams (miner)	*Select Committee* 1864: 10
59	1862	Swan River, Cranbrook (EP892512)	Tr	Z. Williams (miner)	*Select Committee* 1864: 20
60	1862	Tugrah DQ413378	LP	Anon.	Burns 1964: 222, 241
61	1862	Red Rock (Merrywood) EP793748	Tr	Z. Williams (miner)	*Select Committee* 1864: 20
62	1863	Mangana (EP710970)	LP	T. Stephens (school inspector & amateur geologist)	*Proc. R. Soc. VDL* Apr. 1863
63	1869	Tin Dish Rivt, York Plains	Tr	Charles Gould (geologist)	Gould 1869
36A	<1864 (?redisc.)	Gordon (EN195100)		Abbott	*Select Committee* 1864
64	1875	Breadalbane (Big Cutting) EQ185005	L	?R.M. Johnston	Johnston 1873: 42
65	1874	Tullochgorum (EP740870)	L	Grant	Johnston 1875: 58
66	1876	Cygnet EN125784	UP	?T. Nichols	*Proc. R. Soc. Tasm.* (1876): 70
67	<1876	Kaoota (EN132368)	Tr	J. Hurst (coal merchant)	DoM lease files
9A	(redisc.)	Randalls Bay EN100120	UP	Anon.	Thureau 1881a
68	<1880	Dulverton DQ488232	LP	Anon.	DoM lease files
69	<1881	Flynns Creek, Pelverata (EN089376)	Tr	Anon.	Thureau 1881b
70	<1886	Carr Villa (EQ140095)	L	Anon.	*Tasm. Sec. Mines Rep.* 1885–1886: 9
71	<1886	Compton, Old Beach EN228633	Tr	Brock	Johnston 1887: 155–156
72	<1886	Belmont (EP085948)	L	Ritchie	*Tasm. Sec. Mines Rep.* 1885–1886: 10
73	<1886	Longford (EQ096012)	Tr	Anon.	DoM UG Plan 252; *Examiner* 29 June 1886
58A	1887 (redisc.)	Dalmayne	Tr	McMillan & Inglis†	DoM lease files

Item	Date	Locality	Age	Discoverer	Reference
74	<1888	Waratah (CQ765135)	L	Anon.	Nye 1923
75	<1888	Magnet Range (top of) (CQ718128)	L	Anon.	Johnston 1888: 290
76	<1888	Long Bay (Strahan) (CP618310)	L	Anon.	Johnston 1888: 294
77	<1888	Rostella (EQ046245)	L	Anon.	Johnston 1888: 275
78	<1888	Macquarie Plains (junction of Derwent & Styx Rivers (DN922710)	L	Anon.	Johnston 1888: 289
79	<1888	Hastings DM909960	Tr	Anon.	Johnston 1888: 191
6A	1888 (redisc.)	Coal Head (Macquarie Harbour)		C.J. Peever†	DoM lease files
80	1888	George Town DQ892491	UP	M.J. Hackett*	Twelvetrees 1904
81	1889	Port Sorell DQ655423	L	W. Barrett*	DoM lease files
82	1891	Henty River (CP568480)	L	?T.P.H. Jones	Johnston 1892 (1891): 12
83	1891	Gould Point (Farm Cove) (CP750085)	L	H.E. Bowcher*	DoM lease files
84	1891	Henty River (CP590460)	LP	Anon.	Montgomery 1891: 42
63A	1892 (?redisc.)	Evandale Junction	L	Anon.	Montgomery 1892: 13
40A	1892 (prob. redisc.)	Storys Creek (at 4000 ft – 1200 m)		Anon.	Montgomery 1892: 26
85	1892	Mt Pelion East (DP217657)	UP	?Joseph Will	Montgomery 1893: 2
86	1892	Argenton (5–6 miles S of, probably close to railway line on or west of the Professor Range) CP645495	L	Anon.	*Tasm. Sec. Mines Rep.* 1896–97; Lease map Dep. of Mines
50A	1892 (?redisc.)	Plenty		Anon.	Montgomery 1892: 13
87	1892	Ida Bay (DM920884)	Tr	Anon.	Twelvetrees 1902c
88	1892	Mt Ossa	UP	Mole Creek & Zeehan Min. Prospecting & Exploration Co.	Montgomery 1893
89	1892	Mt Pelion West (DP170684)	UP	Mole Creek & Zeehan Min. Prospecting & Exploration Co.	Montgomery 1893

Item	Date	Locality	Age	Discoverer	Reference
90	1892	Barn Bluff (DP120790)	LP	J. Will (prospector)	Montgomery 1893: 2
91	1894	Middleton Creek, Corinna (CP403887)	L	Anon.	Thureau 1894
43A	1897	Mt Byron	UP	T.H. Turner, S.L.A. Moore	DoM lease files
?89A	1898	Mt Pelion West	UP	W. Aylett & P.H. Parsons*	DoM lease files
92	1900	Catamaran DM882782	Tr	Major L. Hood	*Tasm. Sec. Mines Rep.* 1900: xiv
93	1900	Moss Glen DM897803	Tr	G.H. Smith*	DoM lease files
94	1901	Preolenna CQ760440	LP	W. Matthews, J. Wilson, T. Harris, D. Lowrie (track cutters)*	Twelvetrees 1903
95	<1901	Eden (south of) (CP588480)	UP	Woodcutters	Twelvetrees 1901
96	<1902	Mike Howes Marsh (EP211216)	Tr	Anon.	Twelvetrees 1902b
97	1902	Stanhope, Mt Christie EP542817	Tr	J. Stevenson*	Twelvetrees 1906
83A	1902 (?redisc.)	Henty River (thin seams in sandstone near the Henty River) (CP590460)	LP	Anon.	*Tasm. Sec. Mines Rep.* 1902
98	1908	Strathblane (DM928989)	Tr	Woods & W. Anderson	Twelvetrees 1915
99	1909	Meander ("on branch of Meander River, 9 miles west from P.O.") (prob. S)	?UP	E.A. Woodberry*	DoM lease files
100	<1911	Kimberley (DQ565159)	L	Anon.	Twelvetrees 1911: 32
101	<1914	Berriedale (EN205605)	Tr	Anon.	Alexander 1986: 100
102	<1914	Springfield EN228558	Tr	Anon.	Alexander 1986: 100
103	<1914	Triffetts Pt (= Cadbury Point) (EN228623)	Tr	Anon.	Alexander 1986: 100
104	1915	Rocky Plains Bay DM692765	L	W.H. Twelvetrees (geologist)	Twelvetrees 1915: 16–18
105	1916	Mt Paul FP037422	Tr	C.J.Q. Lyne* (farmer and landowner)	DoM lease files

Item	Date	Locality	Age	Discoverer	Reference
106	1917	Ben Lomond (Coal Mine Crag) (EP535985)	Tr	J.B. Dean &F.R. Davis*	DoM lease files; also Hills *et al.* 1922: 214
107	<1919	Great Fitzroy (near Meunna) (CQ765478)	LP	Anon.	*Tasm. Sec. Mines Rep.* 1919
108	1919	?Myrtle Hill (= Johns Hill) Irishtown (CQ458682)	L	McGillivray*	Nye *et al.* 1934: 55; DoM Reward leases
109	1919	Hagley (Rosevale) (DQ966115)	L	L. Gatenby	*Tasm. Sec. Mines Rep.* 1919: 32
110	<1922	Dawsons Siding (mouth of Caroline Creek) DQ498304	LP	Anon.	Hills *et al.* 1922: pl.xxxiv; Dix *in* Jennings 1979: 107
111	<1922	Old Mans Rivt EP834228	Tr	Anon.	Hills *et al.* 1922: 104
112	1922	Lune River	Tr	Anon.	Hills *et al.* 1922: 169
113	<1922	Brambletye (W side of Bonneys Plains) (EP504741)	Tr	Anon.	Hills *et al.* 1922: 30, 212
114	1922	Buckland EN574935	Tr	A.E. French*	DoM lease files
115	<1924	Northdown DQ592447	L	Anon.	Nye 1928
116	<1924	Harford — Iles & Parsons DQ594363	L	Anon.	Reid 1924: 29, 102–103
117	<1924	Harford (Burgess) DQ608344	L	Anon.	Reid 1924: 29, 104–105
118	<1924	Sassafras Driscolls DQ554319 Ingrams DQ556309	L	Anon.	Reid 1924: 30
119	<1924	Dunorlan (DQ603069)	L	Anon.	Reid 1924: 94
120	1929	Rose Rivt (EQ216013) (from 201021–231016)	L	Anon.	Nye 1929
121	1930	Sea Elephant River (King Island) (BR500900)	L	R. Hooper	Carey 1946
122	1930	Mt Elephant (FP035905)	Tr	A.E. Cooper*	DoM lease files
123	1934	Edith Creek (near Lileah) (CQ460614)	L	Anon.	Nye *et al.* 1934: 55
124	1938	Rooks River (Cape Barren Island) (ER975325)	L	Anon.	Blake 1938: 3
125	<1952	Mt Lloyd (DN930509)	Tr	L. Teakle	Hughes 1952
126	1955	Adamsons Peak (DN872205)	UP	Anon.	Hughes 1955
127	1960	Wesley Vale (1.2 km N of) (DQ540410)	L	Anon.	Hughes & Burns 1961(60): 198

Item	Date	Locality	Age	Discoverer	Reference
128	1960	Hastings Caves Road (DM895938)	L	Anon.	Hughes 1960: 32
129	1960	Relapse Creek (West Takone) (CQ726412)	LP	B. Farquhar	McNeil 1961; Hughes 1962(61): 55
130	1979	Tower Hill (East Tower) (EQ716002)			Cornwall Coal Co. drilling
131	1981	Woodbury (EP370330)	Tr	Victor Petroleum (on advice from S. Forsyth, geologist)	
132	1983	Kempton EN130964	Tr	C.A. Bacon (geologist)	DoM unpubl. rep. 1983/33
133	1986	Rabbit Marsh, headwaters of Nile River EP489965	Tr	J.L. Everard (geologist)	J. Everard (pers. comm.)
134	1988	Bushy Park (DN918720)	L	P. Plummer (fireman)	C. Bacon (pers. comm.)

APPENDIX 2

Years of Operation of Tasmanian Coal Mines

Dates of opening and operation of coal mines in Tasmania; based predominantly on returns of production to Department of Mines, partly on historical sources. Mines have been listed in chronological order within a decade of first operation. The letters in brackets after the name of a mine indicate the field or general area in which the mine lies. The letters have the following meanings: A – Avoca; Ck – Colebrook; Cn – Catamaran; Ct – Cygnet area, widely interpreted; DV – Derwent Valley; EC – East Coast; F – Fingal, Mt Nicholas, St Marys; M – Mersey district; Md – Midlands; N – northern Tasmania; NW – northwestern Tasmania; S – south, Hastings area; SPR – St Pauls River; TP – Tasman Peninsula.

1800–1809
Richmond, possibly 1804–1805; 1841–42

1830–39
Saltwater River (TP), 1834–77
Mt Communication (TP), 1836

1840–49
Jerusalem (Ck), 1841–44, 1879–90, 1894, 1910–11
Southport (S), 1842
Schouten Island (EC), 1843–44, 1848–50, 1888–92
Denison Rivulet (EC), 1849–58
Recherche (Cn), 1840's (year unknown)

1850–59
Bott Gorge (M), 1851–57
New Town (DV), 1851–?53, 1872–76, 1883, 1910–11
Denny (M), 1853–54
Tarleton (M), 1853–55
Alfred (M), 1855–83
Denison (M), 1855–59
Don (M), 1855–83
Nook (M), 1855, 1931, 1938–42
Triabunna (EC), 1855

1860–69
Sherwood (M), 1861
Mersey (M), 1861–90
Seymour (EC), 1863–80, 1923–31, 1959–64
Gordon (Rookwood) (Ct), 1864–79
Merrywood (SPR), 1864, 1945, 1948–52, 1953–63, 1985–86
Tugrah (M), 1865–83
Russell (M), 1867–99

1870–79
Back River (EC), 1874, 1921
Adventure Bay (Ct), 1878–81 ... to 1890's

1880–89
Flynns Creek (Ct), pre-1881
Randalls Bay (Ct), pre-1881
Douglas River (EC), 1881–82, 1886, 1901–1902, 1905–1908, 1914–25
Kaoota (Ct), 1881–1910, 1917–19, 1937–71
Mount Cygnet (Ct), 1881–1923
Rileys Mines (M), 1881–1900
York Plains (Md), 1883–1902, 1905-47
Cornwall (F), 1886–1964
Norwich (N), 1886–1919
Dalmayne (F), 1887–92, 1915–19, 1939–53
Hastings (S), pre-1888
Mt Nicholas (F), 1888–1956
George Town (N), 1889

1890–99
Bayntons Tasma, Colebrook (C), 1892–97, 1911
Ben Lomond (Storeys Creek) (A), 1892
Ida Bay (S), 1892, 1909–11
Jubilee (F), 1897–1902, 1920–60

1900–1909
Hood Workings (Cn), 1900-1910
Cardiff (F), 1901–14, 1917, 1966
Moss Glen (Cn), 1902–12
Spreyton No.1 (M), 1902–1903
Glen Leith (Ck), 1903
Illamatha No.1 (M), 1903–42
Marialva (Ck), 1903–1904
Preolenna (NW), 1903–13, 1918–24
Spreyton No.2 (M), 1903–1904
Spreyton No.3 (M), 1904–1908
Brightburn (M), 1905
Buena Vista (A), 1905
Spreyton No.4/Mersey/Allisons (M), 1909–16
Heaney (Ct), 1900's

1910–19
James Workings (Cn), 1910–12
Lewis Hill (SPR), 1910–20
Strathblane (S), 1910–15
Aberdeen (M), 1913–50
New Main Shaft (Cn), 1913–14
Pateena (N), 1916–19
Mt Paul (EC), 1916
Spreyton No.5 (M), 1917–23
Great Fitzroy (NW), 1919

1920–29
Fingal (F), 1920–65
Silkstone (F), 1920, 1950–51
Buckland (Sand River) (EC), 1921
Impression Bay (TP), pre-1922
Sloanes (M), pre-1922
Lune River (S), 1922
Dawsons Siding (M), 1923–25
Mackenzie Workings (Cn), 1923–30
Stanhope (Excelsior) (A), 1923–57

Meunna/Torban Hill (NW), 1925–28, 1935–36
Anthracite Workings (Cn), 1927

1930–39
Coventry No.1 (M), 1931–39
Dulverton (M), 1931–39
Esk Bank (M), 1931–38
Hard-to-get (M), 1931–37
Last Chance (M), 1931–33
Lucky Hit (M), 1931–38
Lucky Nook (M), 1931
Ribbon Workings (Cn), 1931
Southern Star (M), 1931–36
Star (M), 1931–32, 1934–37
Black Beauty (M), 1933–44
Dulverton Tribute (M), 1933–34
Stronach Tunnel (Cn), 1934
Brickyard (M), 1935–36
McCreghan & Sons (M), 1937–38
Botts No.2 (M), 1938
G. Jeffrey (M), 1938
Langloh (DV), 1938–63
Novelty (M), 1938–39
Sheehans (M), 1938
Shepheard & party (M), 1938
J. Bott (M), 1939
Bott & Jeffrey Bros (M), 1939
Botts (M), 1939–42
Coventry No.2 (M), 1939–46
Gordon Workings (Ct), 1939–40

1940–49
Mt Christie No.1 (A), 1940–57
Illamatha No.2 (M), 1943–61
Duncan (F), 1946–present

1950–59
Tasmania (F), 1954–57, 1962–63
Barbers (F), 1955–64
Mt Christie No.2 (A), 1958–63
New Stanhope (A), 1958–71

1960–69
None

1970–79
None

1980–
Blackwood (F), 1981–present
Fenhope (A), 1981–present

APPENDIX 3

Reasons Given for Closure of Coal Mines in Tasmania

Period/Mine	A (i)	A (ii)	A (iii)	A (iv)	B (i)	B (ii)	B (iii)	B (iv)	C (i)	C (ii)	C (iii)	C (iv)	D (i)	D (ii)	D (iii)	D (iv)
1850–1900																
Schouten Island													x			
Douglas River										x						
Seymour										x				x		
Saltwater River	x	x														
Adventure Bay														x		
Mersey																
(10 small mines)	x			x												
1901–1920																
Cardiff			x													
Dalmayne														x		
Catamaran																
– Hoods									x							
– James						x				x						
– Main Shaft									x							
Strathblane									x							
1921–1940																
Preolenna, Meunna									x							
Catamaran																
– Ribbon									?							
– Stronach			x													
– McKenzie					x											x
Cygnet	x															
Seymour									x							
Mersey																
(15 small mines)	x					x			?							
1941–1960																
Mt Christie 1				x												
Stanhope	x			x				x			x					
Mt Nicholas												x				
York Plains				x												
Tasmania				x												
Fingal											x					
Barbers (Valley)											x				x	
Aberdeen	x															
Illamatha 1	x															
Jubilee				x												
Mersey																
(three mines)											x					
Dalmayne				x												
1961-1980																
Merrywood											x					
Langloh				x												
Cornwall							x	x			x					
Kaoota				x												
Mt Christie 2	x															
New Stanhope	x															
Illamatha 2											x					
	9	1	2	9	1	2	1	2	5+2?	3	7	1	1	3	1	1

Classification of Reasons

A.	Geological causes
(i)	mined out or nearly so
(ii)	poor quality coal
(iii)	reached a fault
(iv)	badly faulted or deteriorating geological conditions
B.	Mine failures
(i)	flooding
(ii)	collapse(s)
(iii)	floor heave
(iv)	fire
C.	Economic causes
(i)	lack of capital
(ii)	overcapitalisation on infrastructure
(iii)	loss of markets
(iv)	taken over and closed
D.	Fortuitous causes
(i)	lease not renewed; Government planned a probation station in the same area.
(ii)	jetty washed away
(iii)	pony died before replacement was trained
(iv)	demarcation dispute on the Hobart wharves.

AN ANALYSIS OF THE COMMUNITY COMPOSITION OF THE *XIPHOPHORA GLADIATA* DOMINATED SUBZONE OF THE TASMANIAN SUBLITTORAL FRINGE

by E. L. Rice

(with five tables and nine text-figures)

RICE, E.L., 1989 (31:x): An analysis of the community composition of the *Xiphophora gladiata* dominated subzone of the Tasmanian sublittoral fringe. *Pap. Proc. R. Soc. Tasm.* 123: 191–209. ISSN 0080–4703. Biological Sciences Branch, Department of Fisheries and Oceans, Halifax Research Laboratory, PO Box 550, Halifax, Nova Scotia B3J 2S7, Canada; formerly Department of Botany, University of Tasmania.

The rocky shore sublittoral fringe of the oceanic coasts of Tasmania contains a subzone dominated by the large brown alga *Xiphophora gladiata*. The community composition of this subzone is here examined at fourteen sites. The phytal and faunal assemblages are analysed by principal co-ordinate, classification and nodal analyses. This subzone is found to have a high species richness, including species which had been thought to occupy only higher or lower tidal levels. It is suggested that both plant and animal assemblages are strongly influenced by wave exposure, freshwater run-off and geography.

Key Words: marine community composition, sublittoral fringe, *Xiphophora*, multivariate analyses.

INTRODUCTION

The rocky shores of southeastern Australia are known to be occupied primarily by barnacles and molluscs in the upper intertidal (Underwood 1981), while algae dominate at midshore level and below. In particular, the sublittoral fringe zone characteristically has a canopy of various species of large brown algae, many of which are restricted to this zone, with often two or three understorey species below the canopy (Womersley 1981). The algal and animal communities of this fringe on Tasmanian rocky shores are not well known. Intertidal studies (Guiler 1952a,b, 1954, Guiler *et al.* 1958, Bennett & Pope 1960, King 1973, Saenger 1974) generally make little detailed reference to this level, beyond mentioning indicator species. The few subtidal studies (Cribb 1954, Edgar 1983a,b, 1984) have mainly been concerned with greater depths and were restricted to a few specific locations.

In very exposed, rocky areas on the oceanic coasts of Tasmania, this sublittoral fringe is dominated by the alga *Durvillaea potatorum* (Bennett & Pope 1960, Edgar 1984). With increasing levels of shelter, *Durvillaea* is replaced by *Xiphophora gladiata*, *Lessonia corrugata*, *Phyllospora comosa* and other algae (Edgar 1984). On shores where *Xiphophora* is not itself the dominant sublittoral fringe species, it often occurs in a thin band just above the dominant species (Bennett & Pope 1960). Thus, on the oceanic coasts of Tasmania it is possible to define a *Xiphophora* subzone, dominated by *X. gladiata*, which marks the highest limit of the sublittoral fringe on very exposed shores and represents the upper sublittoral zone on moderately exposed ones. This paper is a description of the assemblage of species in this subzone.

MATERIALS AND METHODS

The geographic range of *Xiphophora gladiata* ssp. *gladiata* (*sensu* Rice Kenchington 1987, Rice 1989), and hence of the subzone, is restricted to the oceanic east, south and west coasts of Tasmania. Samples were collected at fourteen sites distributed throughout this area and the sites grouped into several geographic regions to facilitate the interpretation and discussion of results (table 1). The D'Entrecasteaux Channel and Southwest regions are distinctive in that they are heavily influenced by the tannin-rich run-off of the Huon River and the Old and Spring Rivers respectively. The other sites were mainly on exposed, open coasts.

At each site, two 0.25 m^2 grids were randomly placed within a distance of 10 m of each other in the *Xiphophora* subzone. These grid and sample sizes were predetermined by the requirements of a

TABLE 1

Sampling Sites with Details of their Environment

Region/Geology Site code/Site	Latitude	Longitude	Exposure index*	Sampling date
Northwest/Precambrian orthoquartzite bedrock				
(1) West Point	40°56'S	144°37'E	26	16.11.85
(2) North Mawson Bay	40°56'S	144°37'E	27	17.11.85
(3) Bluff Hill Point	41°01'S	144°37'E	28	16.11.85
West/Precambrian metaquartzite bedrock				
(4) Cape Sorell	42°12'S	145°10'E	14	3.11.85
Southwest/Precambrian metaquartzite bedrock and boulders				
(5) Bathurst Channel†	43°20'S	146°00'E	01	27.02.85
(6) Bramble Cove†	43°19'S	145°59'E	02	25.02.85
(7) Spain Bay†	43°22'S	145°58'E	06	25.02.85
D'Entrecasteaux Channel/Jurassic dolerite boulders with a Permian limestone bedrock outcrop at White Cliff				
(8) Verona Sands†	43°17'S	147°09'E	05	20.09.85
(9) Ninepin Point†	43°17'S	147°10'E	15	23.09.84
(10) White Cliff†	43°17'S	147°11'E	10	20.09.85
Southeast/Permian glaciomarine sandstone bedrock				
(11) Blowhole (Tasman Peninsula)	43°02'S	147°57'E	12	20.09.85
Northeast/Devonian granodiorite bedrock				
(12) Burns Bay†	41°17'S	148°21'E	07	26.09.85
(13) Skeleton Bay†	41°15'S	148°19'E	08	26.09.85
(14) Gardens Shoal	41°10'S	148°17'E	21	26.09.85

* By Baardseth's (1970) method.
† Sampled with the aid of SCUBA.

study of geographic morphological variation in *Xiphophora gladiata* ssp. *gladiata* (Rice Kenchington 1987). The resulting survey design may have been less than ideal for the present ecological purposes. In particular, the small area sampled at each site (0.5 m^2) may have led to the non-recording of rare species or those occurring in rare patches. At a few sites, however, the *Xiphophora* subzone is so narrow that the 0.5 m side of the grid could have projected both into the eulittoral and into *Durvillaea*-dominated parts of the sublittoral fringe. In practice, at two sites (Ninepin Point and White Cliff) the average number of species per 0.25 m^2 grid was the same as that for 1 m^2 grids (Rice Kenchington 1987), suggesting that any loss of rarities was minor. Similarly, at the few sites sampled where the presence of *Durvillaea* reduced the *Xiphophora* subzone to a narrow fringe, care was taken to reject any random grid placement that would have extended beyond the subzone. Thus, the survey design was considered sufficient for present purposes.

All *Xiphophora* plants in each grid were harvested, by cutting with a sharp knife as close as possible to the substratum, and bagged. After the removal of *Xiphophora*, all other macroscopic benthos in the grids, including both algae and animals, were collected and separately bagged. At some sites this procedure was performed underwater by SCUBA diving (table 1). At others, sampling was conducted when the main bed of

Xiphophora was exposed at low tide. All material was transported to the laboratory on ice in a large insulated container. On arrival, it was frozen and held at –20°C until processed. Additional epifloral and epifaunal species, as well as unattached animals living among the *Xiphophora* fronds, were collected from these plants in the laboratory. The *Xiphophora* plants were carefully searched for epiphytes, as each plant was examined in detail for inclusion in a morphometric study of that species (Rice Kenchington 1987).

All plants and animals collected were identified to species level where possible, or else to the lowest possible taxon, using the available keys and guides (Hale 1927, 1929, Fritsch 1935, 1945, May & Macpherson 1958, Dixon 1958, Macpherson & Gabriel 1962, Cotton 1964, Womersley 1964, 1967, 1984, Saito & Womersley 1974, Westcott 1976, Bold & Wynne 1978, Ponder & Creese 1980, Kaas & van Belle 1980, Dartnall 1980, Fuhrer *et al.* 1981, Shepherd & Thomas 1982, Marine Research Group of Victoria 1984, Phillips 1984, Johansen & Womersley 1986). Assistance with identifications was provided by Miss A Green, Mrs L. Turner, Dr J. Phillips and Prof. H.B.S. Womersley. Representative collections of the invertebrate animals were deposited in the Tasmanian Museum and the Zoology Department, University of Tasmania collections. Herbarium sheets of the algae were lodged at the Tasmanian Herbarium (HO), located in the grounds of the University of Tasmania.

A wave exposure index was determined for each site using the cartographical method of Baardseth (1970). The value of this index is equal to the number of 9° sectors, radiating from the site, which are open to the sea for 7.5 km or further.

Data Reduction and Preparation

For analysis, the data were recorded as presence or absence. Such binary data is less informative than abundances (Clifford & Stephenson 1975), but this loss of information was considered preferable to introducing spurious "abundance" differences into the data. The data set was not reduced by the elimination of rare species. More than half of the species found were recorded at only one site and the elimination of these singletons, let alone species found at only two or three sites, would waste much of the information content of the data. The retention of these rare species, however, will have led to the inclusion of extra "noise" in the data set with any given survey effort, since their distributions cannot be recorded with the same precision as that of a common species. The singleton records did not usually represent the presence of a single individual in the collections, but rather many individuals from one place. Indeed, in many cases these species were recorded from both grids at their site of occurrence.

The records of amphipods and isopods required special treatment. These animals were mostly found amongst the bagged *Xiphophora* and, indeed, this is an established underwater collecting technique for such species (Edgar 1983a,b,c) However, where the *X. gladiata* was harvested while semi-exposed at low tide, only those species of amphipods and isopods which retreat among or clasp its fronds could be so collected. Following examination of the field data, it was concluded that only the large (c. 10 mm) isopod *Amphoroidea elegans* was adequately sampled at all sites. It clings tenaciously to *X. gladiata*, while its size and bright orange colour make it easy to detect amidst the alga. All other isopods and all amphipods were eliminated from the analyses. No further data reduction was considered necessary.

The species lists for the two 0.25 m^2 grids at each of the fourteen sites were combined for these analyses. However, the plant and animal data sets were analysed separately, as these two components of the community were expected to have different ecological response patterns.

Analytical Methods

From each data set, two similarity matrices were calculated, one for species (R-mode) and one for sites (Q-mode), using the Dice (1945) coincidence index. The Dice index expresses the number of shared descriptors as a proportion of the richness of the objects being compared (cf. Faith *et al.* 1987). This coefficient is almost linear with ecological distance, until the number of shared species approaches zero (Dr P. Minchin, pers. comm.).

The sites and species were classified using an agglomerative, hierarchical ("SAHN": Sneath & Sokal 1973), clustering algorithm with average linkage between groups ("UPGMA": Sneath & Sokal 1973), using the CLUSTER subprogram of SPSS^x (SPSS Inc. 1986).

The resulting classifications were compared using nodal analysis (Colvocoresses & Musick 1984) in which the "constancy" and "fidelity" of each species group to each site group are compared. For this, each dendrogram is divided into a series of groups, defined at some arbitrarily chosen level of similarity. The "constancy" of a species group at

a site group is then computed as the ratio of the number of occurrences of the species in the former group at the sites in the latter group to the total number of possible occurrences (the product of the number of species in one group and the number of sites in the other). From these "constancy" values, "fidelity" is calculated as the constancy of a species group at a site group divided by its average constancy over all site groups. "Constancy" ranges from zero (no occurrences) to unity (every species in the species group is ubiquitous throughout the site group). "Fidelity" has a value of one for site groups with average constancy (for a given species group) and is greater than one where the species group has above average occurrence at a site group.

The matrices of similarity (S) were transformed into matrices of distance (D) (Legendre & Legendre 1983) by:

$$D = -0.5\ (1 - S)^2.$$

The sites and species were then ordinated by Principal Co-ordinates Analyses (Gower 1966) of these distance matrices, calculated by the PCORD macro of GENSTAT (Alvey *et al.* 1977). This technique allows a free choice of similarity coefficient (unlike Principal Components or Factor Analyses), while preserving undistorted the spatial relationships between the objects, and hence allows the advantages of the Dice index to be carried into the ordination (Clifford & Stephenson 1975, Legendre & Legendre 1983).

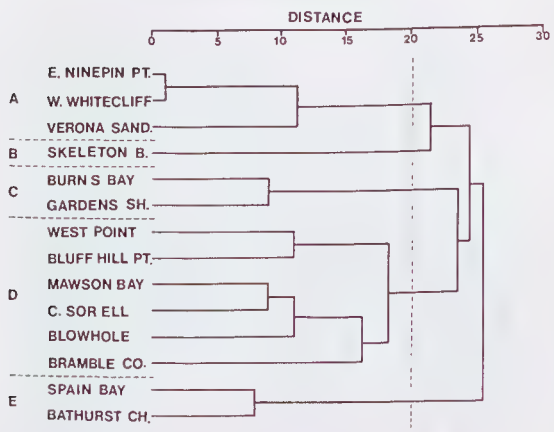

FIG. 1 — A dendrogram of the study sites classified by algal species occurrences at the sites. The broken line is the distance selected at which to examine site groupings.

RESULTS AND DISCUSSION

The plants and animals collected from the *Xiphophora* subzone are listed in tables 2 and 3 (pp. 202–205) respectively. These tables include species from all areas and show the occurrence of each species at each site. Species directly associated with *X. gladiata*, either as epiphytes or as free-living species collected from amongst the fronds of harvested plants, are indicated. Specimens of un-named or unidentified species have been deposited in the Tasmanian Museum or Herbarium. All further results and discussion are confined to data in these tables.

Five algal and six animal species each occurred at one-third or more of the sites: the upright red algae *Laurencia elata*, *Ballia callitricha*, *Corallina officinalis*; the large brown algae *Cystophora xiphocarpa* and *C. subfarcinata*; the prostrate sponge *Callyspongia clathrata*; the isopod *Amphoroidea elegans*; the limpet *Patelloida victoriana*; the large predatory whelk *Thais textilosa*; the mussel *Mytilus edulis planulatus*; and the epiphytic bryozoan *Emma triangula*. These 11 species, plus *Xiphophora gladiata* itself, therefore represent the "core" species of the *Xiphophora* subzone assemblage.

Algae

The dendrogram of sites based on algal species occurrence (fig. 1) shows that geographically-adjacent sites tend to have similar algae. At the arbitrarily chosen similarity level drawn, the three D'Entrecasteaux Channel sites (Group A) cluster together, as do Burns Bay and Gardens Shoal (Group C: northeast Tasmania) and Spain Bay and Bathurst Channel (Group E: southwest Tasmania). However, the largest site group (Group D) contains all of the exposed west coast sites and the exposed Blowhole site, suggesting environmental rather than geographic control. All of the Group D sites, except Bramble Cove, are very exposed. Group C, containing the exposed northeast coast sites, clusters with Group D, thus reinforcing the conclusion that this dendrogram is jointly determined by the effects of exposure and geographic location.

These same data are displayed in figure 2, with the stations ordinated on the first two principal co-ordinate axes of their distance matrix (jointly accounting for 45.6% of the variance). Figure 2 shows similar relationships to figure 1. The four major geographic regions (defined *a priori*) are discrete in this "algal occurrence" hyperspace, even

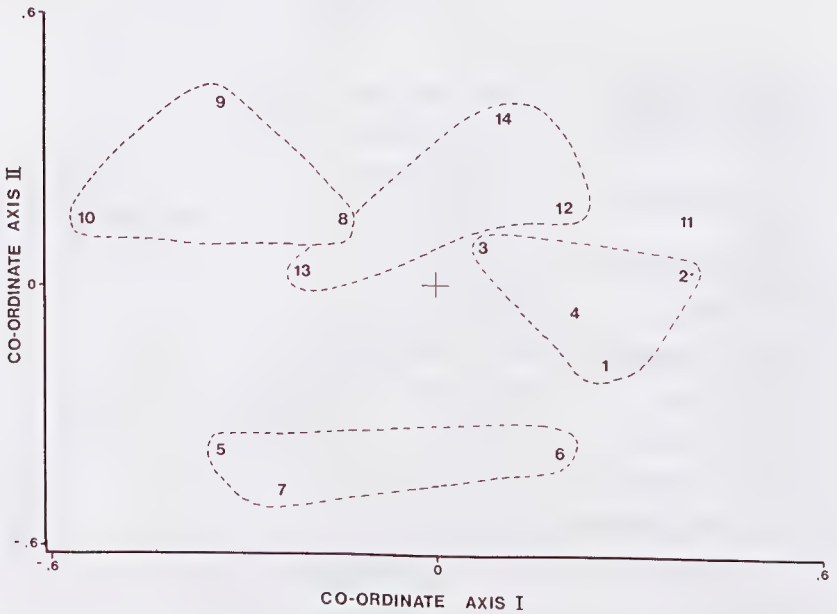

FIG. 2 — A plot of the study sites on the first two principal co-ordinate axes based on the distance matrix of algal occurrence. For site codes see table 1.

when one site of a region lies close to those from another region. The first axis may be related to exposure, with the more exposed sites having higher scores, while the second tends to separate southwestern sites from the remainder. Those southwestern sites are influenced by the tannin-coloured waters of Port Davey, which are known to reduce light penetration and to produce major biological effects (Edgar 1984). Taken together, these analyses indicate that the algal species composition of the *Xiphophora* subzone is influenced to some degree by exposure and geographic position, with perhaps a local effect of tannins near Port Davey.

In the dendrogram of algal species (fig. 3), nine clusters were recognised. Few of these can be explained biologically, given the poor state of present knowledge of the autecology of these species. The Group 1 algae, with the possible exception of *Chaetomorpha aerea*, could be expected to be grazer-resistant because of their chemical constituents. *Sargassum decipiens* is reported to prefer moderately sheltered waters (Womersley 1981). Group 2 contains four species epiphytic on *Xiphophora* (i.e. *Bangia* sp., *Hypnea episcopalis*, *Polysiphonia brodiaei* and *Ceramium* sp.) but this is less than half the recorded epiflora (appendix) or, indeed, half of Species Group 2.

Figure 4 shows these species arranged on the first two principal co-ordinate axes of their distance matrix (incorporating 45.7% of the variance). The same plot is reproduced in figure 5, with contours of distance, from the dendrogram, drawn around the species locations. Apart from two internally highly similar and externally discrete groups (corresponding to Species Groups 6 and 8 of figure 3), these figures show that the species groups are rather diffuse and poorly defined. The first axis appears to be separating species Group 6 from the remainder of the algae, while the other species groups are more clearly arranged on the second axis [from Group 2 (positive), through Groups 8, 1, 5 and 9, to a cluster containing Groups 3, 4 and 7 (negative)].

When these classifications of algal species and sites are combined in nodal analysis (table 4, p. 206), more relationships can be seen. No site group is represented by a single species group, and the larger site groups contain at least one species from most groups; however, some species groups

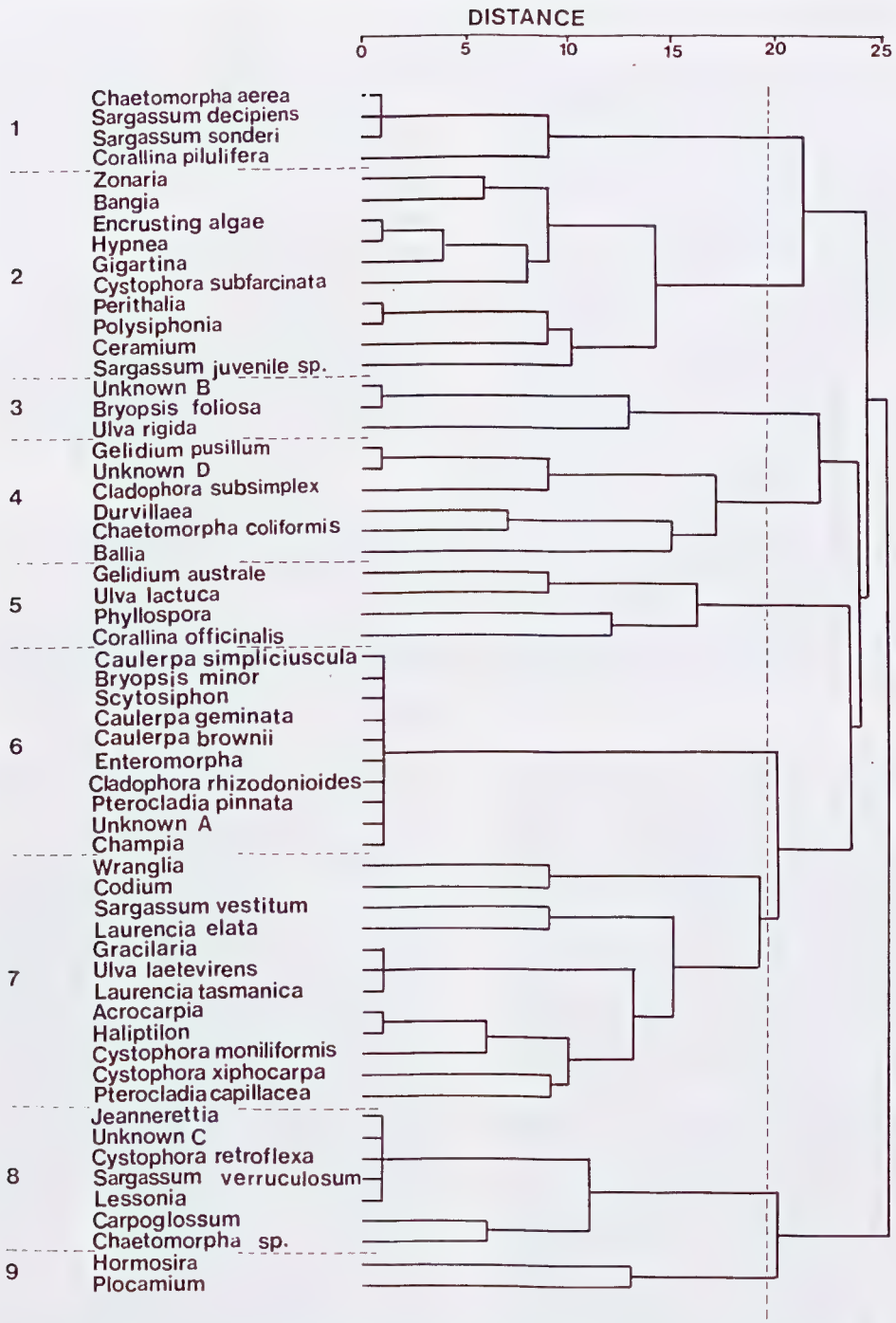

FIG. 3 — A dendrogram of the algal species classified by the sites at which they occur. Full names of the species are given in table 2.

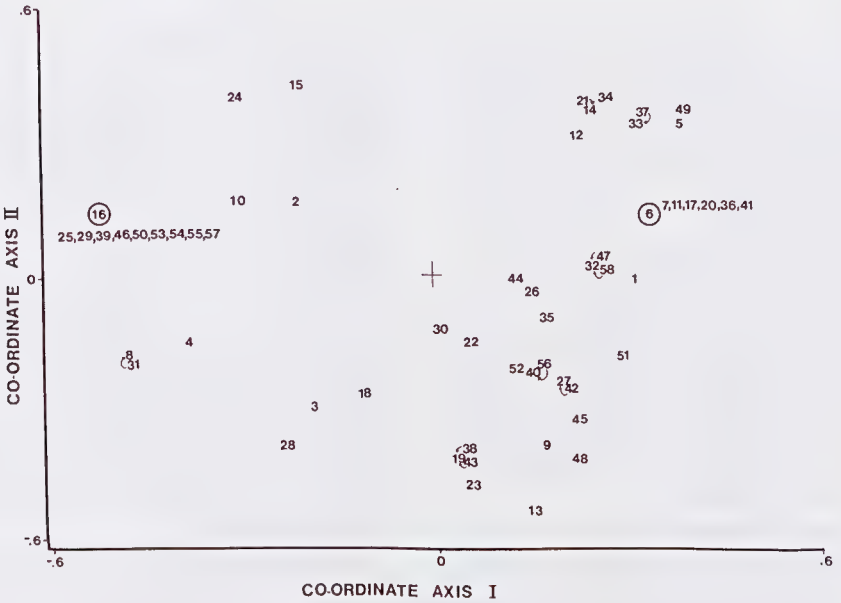

FIG. 4 — A plot of the algal species on the first two principal co-ordinate axes. Species codes are given in table 2. Arrows indicate one or two overlapping values, open circles indicate many overlapping values with the species listed adjacent to the circles.

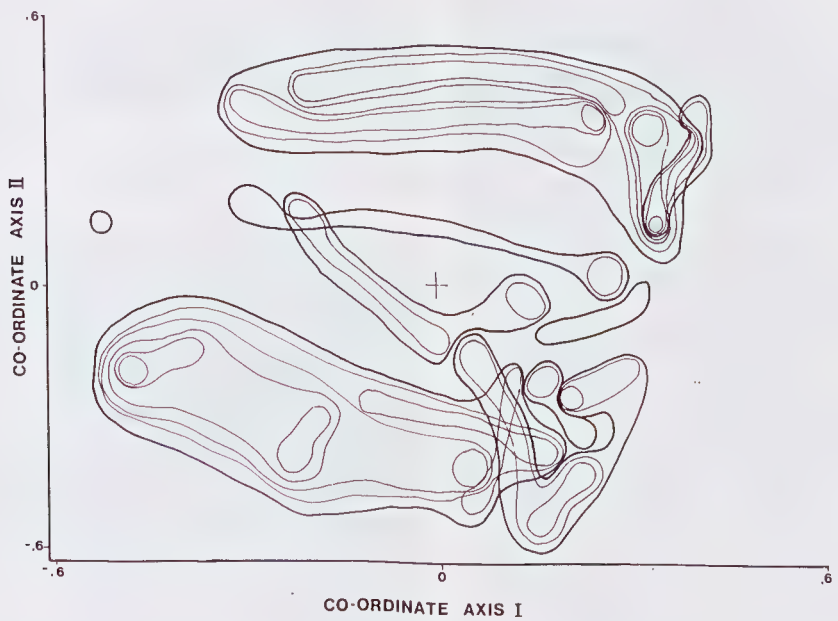

FIG. 5 — Distance contours (refer to dendrogram in fig. 3) drawn around the species groups (fig. 4) plotted on the first two principal co-ordinate axes. Bold lines indicate the grouping at the distance (20) chosen for group definition.

are confined to particular site groups. Species Group 1, representing some of the possibly grazer-resistant plants, was found only at Site Group A, the D'Entrecasteaux Channel, and indeed only at Verona Sands (table 2) in the mouth of the Huon River. Similarly, Species Group 6 is exclusive to Bluff Hill Point. This explains the distinction of this latter group in figures 4 and 5, though only in terms of the analysis and not biologically.

Species Group 2, including four epiphytes, is almost entirely confined to the relatively sheltered waters of the D'Entrecasteaux Channel. Species Groups 3 and 4, on the other hand, are largely absent from those areas, preferring exposed shores (Site Groups C and D) or western shores (Site Groups D and E) respectively. Thus, the second axis in figures 4 and 5 serves to distinguish algae with sheltered, eastern preferences from those with exposed or western tendencies.

Species Group 5 is oddly spread between the D'Entrecasteaux Channel and the Northeast regions. Inspection of table 2 shows it to be composed of two widespread species and two individual species with complete fidelity to Site Groups C and D respectively. Its tabulated constancies (table 4) are, therefore, rather misleading.

Group 7 is widespread, but was found particularly at Skeleton Bay and the exposed western coast. Group 8 was found in the Channel and in both exposed and sheltered western areas. These latter relationships may only be summarising random fluctuations.

When table 4 is examined in the reverse direction, the exposed, western shores of Site Group D are characterised by Species Groups 3, 4 and 7, including the sublittoral fringe indicator species *Durvillaea potatorum*. Of these, only Species Group 4 contributes markedly to the Port Davey tannin-influenced southwestern sites, while the exposed northeastern sites share Species Group 3 and add Groups 5 and 9. The latter plus Group 8 are found at the mouth of Port Davey.

In summary, Species Groups 5, 7 and 8 may be, collectively, the "normal" algal inhabitants of the *Xiphophora* subzone, to which are added Groups 3 and 4 on exposed southern and western shores, Groups 3 and 9 on exposed northeastern shores, Groups 4 and 9 at the mouth of Port Davey, and Group 2 on sheltered eastern shores.

The five "core" species, identified above through individual distributions, fall into Groups 2, 4, 5, and 7, so that there is no close congruence between these two ways (individual *versus* assemblage) of viewing the community.

The remaining unusual feature in these data is the presence of Species Group 6 exclusively at Bluff Hill Point. Some of these species, especially the *Caulerpa*, are usually found at greater depths (Edgar 1983a) though *C. brownii* often occurs in intertidal pools (Bennett & Pope 1960). At Bluff Hill Point they form a dense turf around the *Xiphophora* clumps. These plants probably represent the "algal turf" of exposed lower mid-littoral zones described by Bennett & Pope (1960), into which *Xiphophora* and other species are raised by the extreme wave action at this most exposed of sites.

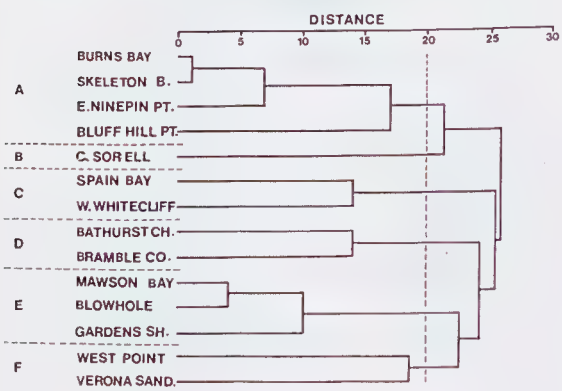

FIG. 6 — A dendrogram of the study sites classified by animal species occurrences at the sites.

Fauna

The analyses of faunal data are less readily explicable. The dendrogram of sites (fig. 6) shows few interpretable clusters. Site Group D comprises the Port Davey tannin-influenced sites and Group E contains only exposed sites, but the remainder of the Groups are of mixed site characteristics. Ordination of these sites (fig. 7) shows that the regions are largely non-overlapping in the space defined by the first two principal co-ordinate axes (43.9% of the variance), but each region occupies a very elongated area, suggesting variable faunal composition. The second axis is clearly negatively related to wave exposure, but the first is not readily interpretable.

The dendrogram of animal species (fig. 8) is more clearly divided into clusters, though they are not biologically interpretable. Ordinating these species on the first two principal co-ordinate axes

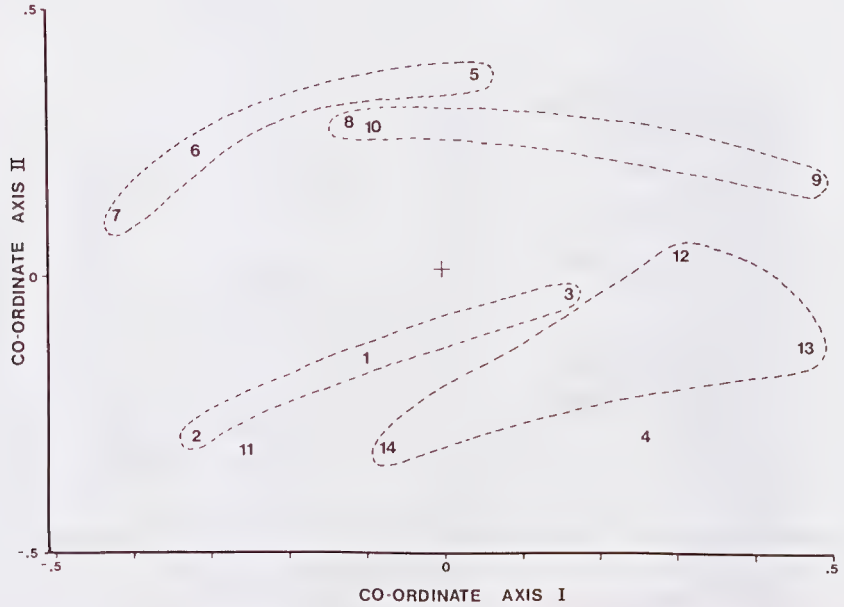

FIG. 7 — A plot of the study sites on the first two principal co-ordinate axes based on a distance matrix of animal occurrence. For site codes see table 1.

(which explain 52.5% of the variance — fig. 9) does show a series of discrete groups, generally following the clusters but displaying more complex relationships.

As with the algal analyses, the nodal analysis (table 5, p. 206) is much more useful. Two species groups, 3 and 5, are more-or-less ubiquitous. Indeed, these contain five of the six "core" animal species of the *Xiphophora* subzone. However, both groups are very diffuse (fig. 9) and the species within them probably have little in common beyond their broad distributions.

The remaining species groups are highly specialised in their sites. Species Groups 1, 2 and 4 are the typical animals of the *Xiphophora* subzone on exposed shores, with Groups 1 and 2 being the species of southern and western areas, while Group 4 comprises those of the northeast.

Species Group 7 was found only at West Point and Bluff Hill Point, the two very exposed northwestern Tasmania sites. It might, therefore, be expected to be associated with Species Groups 1 and 2, though this is not clear in the ordination, suggesting that these two headlands are ecologically less extreme for animals than the Mawson Bay site.

Species Groups 6 and 10 were found primarily at Site Group D, the tannin-influenced Port Davey area sites. Group 10 was characteristic of the very sheltered and very tannin-influenced Bathurst Channel site, though some of its members were also found at the possibly somewhat brackish-water-influenced sites of Verona Sands and Burns Bay. Group 6 was, however, found primarily at the Bramble Cove site (an exception being the anemone *Circophorus*, which is widespread). These species groups can therefore be described as the southwestern or perhaps tannin- or brackish-water-tolerant species.

Species Group 8 was found largely at Site Group F and, within this, almost exclusively at Verona Sands (the link between this site and West Point being here shown to rely on two relatively widespread sponges, *Tethya* and the unidentified poriferan species, and the gastropod *Turbo undulatus*. This species group probably represents the species of areas with boulder substrates, limited wave action and some brackish-water influence. The starfish *Paranepanthia grandis* is known from mainland Australia, but in Tasmania it has only been found in the D'Entrecasteaux Channel and surrounding areas (Dartnall 1980).

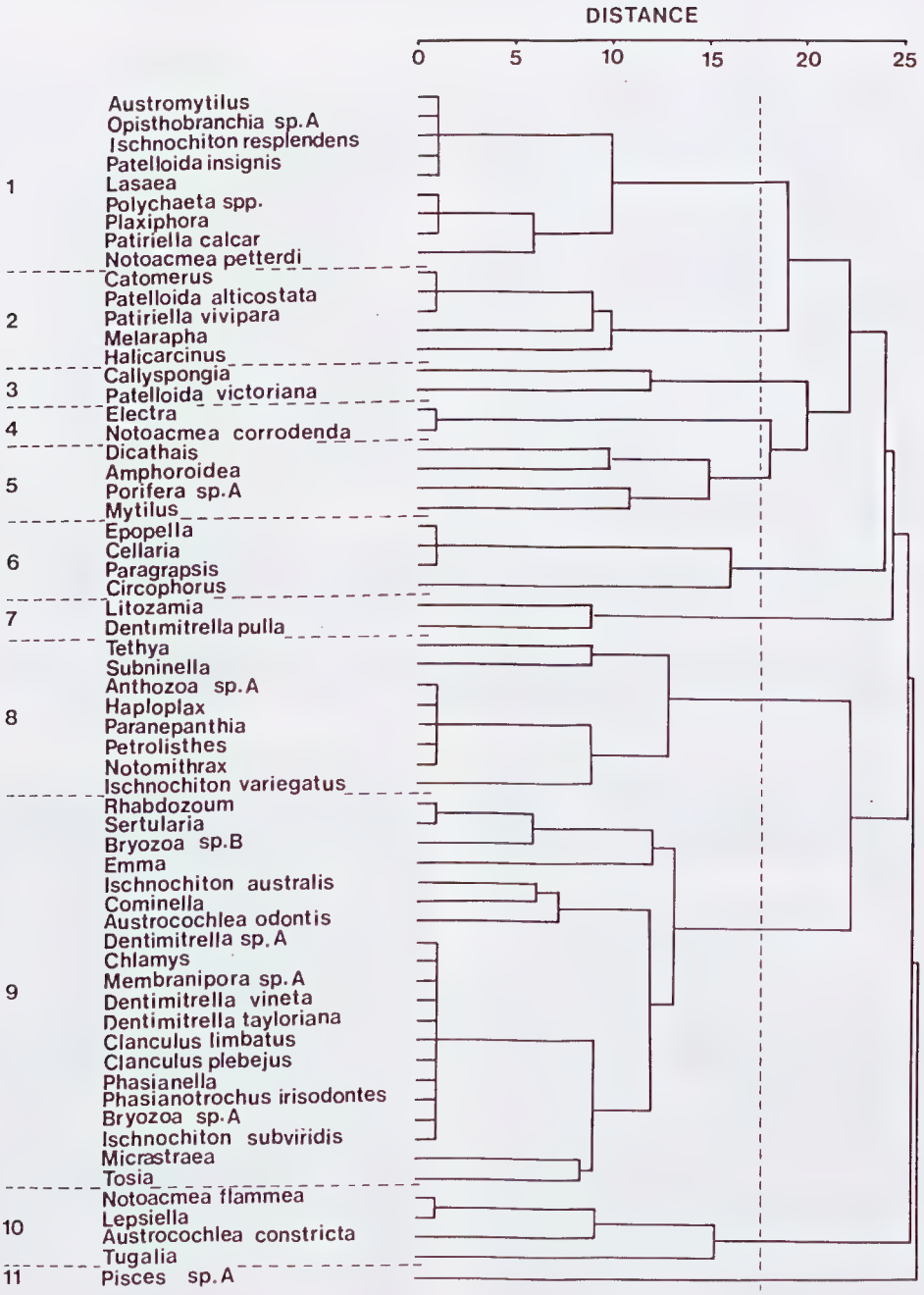

FIG. 8— A dendrogram of the animal species classified by the sites at which they occur. Full names of the species are given in table 3.

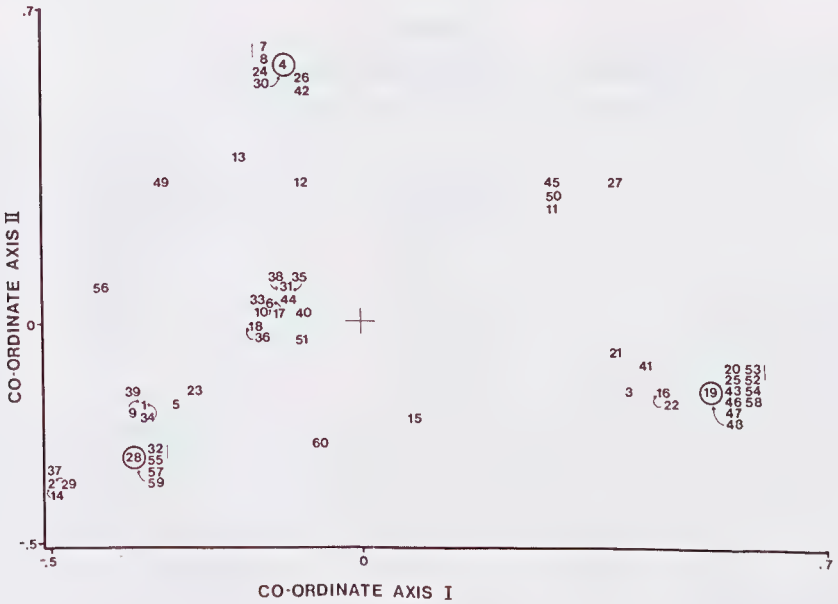

FIG. 9 — A plot of the animal species on the first two principal co-ordinate axes. Species codes are given in table 3. Arrows indicate one or two overlapping values, open circles indicate many overlapping values with the species listed adjacent to the circles.

Species Group 9, the largest, had a strong preference for Site Group C (Spain Bay and White Cliff). Indeed, every species in the group occurred at White Cliff and more than half occurred nowhere else. This species group includes five of the seven byrozoans found plus the only hydroid, suggesting that the D'Entrecasteaux Channel (and, to a less extent, Spain Bay) are desirable areas for small colonial filter feeders, perhaps utilising flocculent material from the river run-off.

The species group is shared with the generally similar site at Spain Bay (four species), Ninepin Point and Verona Sands (three species), Burns Bay and Bathurst Channel (one species each) and, more surprisingly, the Blowhole, Bluff Hill Point, West Point and Gardens Shoal (three species: *Emma triangula*, *Micrastraea aurea*, *Tosia magnifica*). Only two species which occur at White Cliff are not in this species group, showing that the UPGMA, SAHN cluster has been driven by the large number of close similarities in this unit.

Species Group 11, the only fish in the analyses, was found only at Cape Sorell. The other species at that site were all rather widespread and it is the presence of this fish which separates Cape Sorell from the other exposed west coast sites in figure 6.

This interpretation of the nodal analysis also allows some explanation of the failure of the cluster analysis of sites using the animal data. A combination of some common and widespread species with other rare or patchy ones (possibly exacerbated by the use of binary data) caused some disparate sites to cluster together (e.g. West Point with Verona Sands, Bluff Hill Point with Group A) and separated Cape Sorell from the other exposed west coast sites.

TABLE 2

The Occurrence of Algal Species at each of the Sampling Sites

Division Order Species†	Species code	Site code* 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Chlorophyta															
Ulvales															
Ulva laetevirens (L.) Aresch.	43	+	–	–	–	–	–	–	–	–	–	–	–	–	–
U. lactuca L.	44	–	–	–	–	–	–	–	–	–	–	–	–	–	+
U. rigida (L.) C.Ag.	45	–	–	–	+	–	–	–	–	–	–	+	+	–	–
Enteromorpha intestinalis (L.) Link.	46	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Cladophorales															
Chaetomorpha aerea (Dillwyn) Kuetz.	47	–	–	–	–	–	–	–	+	–	–	–	–	–	–
C. coliformis (Mont.) Kuetz.	48	–	+	–	+	–	+	–	–	–	–	+	–	–	–
C. sp.	49	–	–	–	–	+	–	+	–	–	+	–	–	–	–
Cladophora rhizodonioidea Van den Hook & Wom.	50	–	–	+	–	–	–	–	–	–	–	–	–	–	–
C. subsimplex Kuetz.	51	–	–	–	+	–	–	–	+	–	–	–	–	–	–
Codiales															
Codium fragile (Sur.) Hariot	52	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Caulerpales															
Caulerpa geminata Harv.	53	–	–	+	–	–	–	–	–	–	–	–	–	–	–
C. brownii (C.Ag.) Endl.	54	–	–	+	–	–	–	–	–	–	–	–	–	–	–
C. simpliciuscula (Turner) C.Ag.	55	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Bryopsis foliosa Sonder	56	–	–	–	–	–	–	–	–	–	–	+	–	–	–
B. minor Wom.	57	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Rhodophyta															
Ceramiales															
Laurencia elata (C.Ag.) Harv.	18	+	+	+	–	–	–	–	+	–	–	+	+	–	–
L. tasmanica Hook. & Harv. ex Harv.	19	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Jeannerettia lobata Hook & Harv.‡	20	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Polysiphonia brodiaei (Dillw.) Sprengel.§	21	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Ballia callitricha (Ag.) Mont.	22	+	–	+	+	+	+	+	+	–	–	–	–	–	–
Wrangelia spareopsis	23	+	+	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium sp.‡	24	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Rhodymeniales															
Champia viridis C.Ag.‡	25	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Gelidiales															
Gelidium australe J.Ag.‡	26	–	–	–	–	–	–	–	–	+	–	–	+	–	+
G. pusillum (Stack.) Le Jol.	27	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Pterocladia capillacea (Gmel.) Born. & Thur.	28	+	–	+	+	–	–	–	–	–	–	+	–	–	–
P. pinnata (Huds.) Pap.	29	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Cryptonemiales															
Corallina officinalis L.	30	–	+	+	+	–	–	–	+	+	–	+	–	–	+
C. pilulifera Post. & Rupr.	32	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Haliptilon roseum (Lamarck) Gabary & Johansen	31	+	–	+	–	–	–	–	–	–	–	–	–	–	–
Unident. crustal algal sp.	33	–	–	–	–	–	–	–	+	+	+	+	–	–	–
Bangiales															
Bangia sp.‡	34	–	–	–	–	–	–	–	–	+	+	–	–	–	–

Division Order Species†	Species code	Site code* 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gigartinales															
Plocamium angustatum (J.Ag.) Hook. & Harv.‡	35	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Gigartina muelleriana Setch. & Gard.	36	–	–	–	+	–	–	–	+	+	+	–	–	–	–
Hypnea episcopalis Hook. & Harv.‡	37	–	–	–	–	–	–	–	+	+	+	–	–	–	–
Gracilaria secundata Harv.	38	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Unknown red alga sp.A	39	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Unknown red alga sp.B	40	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Unknown red alga sp.C	41	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Unknown red alga sp.D	42	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Phaeophyta															
Fucales															
Hormosira banksii (Turn.) Dec.	01	–	–	–	–	+	+	–	–	–	–	–	+	–	–
Phyllospora comosa (Labill.) C. Ag.	02	–	–	+	–	–	–	–	–	+	–	–	+	–	+
Cystophora xiphocarpa Harv.	03	+	+	+	+	–	–	–	–	–	–	–	–	+	–
C. moniliformis (Esper) Wom. & Niz.	04	+	–	+	–	–	–	–	–	–	–	–	–	+	–
C. subfarcinata (Mertens) J. Ag.	05	–	–	–	–	+	–	–	+	+	+	–	–	+	–
C. retroflexa (Labill.) J. Ag.	06	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Carpoglossum confluens (R. Br. ex Turner) Kuetz.	07	–	–	–	–	+	–	+	–	–	–	–	–	–	–
Acrocarpia paniculata (Turn.) Aresch.	08	+	–	+	–	–	–	–	+	–	–	–	–	–	–
Sargassum vestitum (R. Br. ex Turner) J. Ag.	09	+	–	–	–	–	–	–	+	+	–	+	–	–	–
S. sonderi (C.Ag.) J. Ag.	10	–	–	+	–	–	–	–	+	–	–	–	–	–	–
S. verruculosum (Mert.) C. Ag.	11	–	–	–	–	+	–	–	–	–	–	–	–	–	–
S. sp. (juvenile)	12	–	–	–	–	–	–	–	–	–	+	–	–	+	–
S. decipiens (R. Br. ex Turner) J. Ag.	58	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Durvillaea potatorum (Labill.) Aresch.	13	+	+	–	+	–	+	–	–	–	–	–	–	–	–
Sporochnales															
Perithalia caudata (Labill.) Wom.	14	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Dictyotales															
Zonaria angustata (Keutz.) Pap.	15	–	–	+	–	–	–	–	–	+	+	–	–	–	–
Scytosiphonales															
Scytosiphon lomentaria (Lyngbye) C. Ag.	16	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Lessonia corrugata Lucas	17	–	–	–	–	+	–	–	–	–	–	–	–	–	–

* See table 1.
† Nomenclature follows identification guides cited in text and hence may exclude some recent unpublished revisions.
‡ Epiphytic species.
§ Free-living species found among fronds of *Xiphophora*.

TABLE 3

The Occurrence of Animal Species at Each of the Sampling Sites

Phylum* / Class / Species†	Species code	Site code‡ 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Porifera															
Demospongiae															
Tethya sp.A	11	+	–	–	–	+	–	–	+	–	+	–	–	–	–
Callyspongia clathrata Dendy	12	–	–	+	–	+	–	–	+	+	–	–	+	+	–
Unident. poriferan sp.	13	+	–	–	–	–	–	+	+	–	–	–	–	–	+
Coelenterata															
Hydrozoa															
Sertularia marginata (Kirchenpauer)§	22	–	–	–	–	+	–	–	–	–	+	–	–	–	–
Zoantharia															
Circophorus nutrix (Stuckey)§	23	–	+	–	–	+	+	+	–	–	–	–	–	–	–
Unident. anthozoan sp.	24	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Annelida															
Polychaeta															
Unident. polychaete sp.	14	–	+	–	–	–	–	–	–	–	–	+	–	–	–
Crustacea															
Cirripedia															
Catomerus polymerus (Darwin)	09	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Epopella simplex (Darwin)	10	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Malacostraca															
Halicarcinus ovatus (Stimpson)	05	–	–	+	–	–	–	–	–	–	–	+	–	–	–
Paragrapsis quadridentatus (Milne Edwards)	06	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Petrolisthes elongatus (Milne Edwards)	07	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Notomithrax ursus (Herbst)	08	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Amphoroidea elegans (Baker)¶	60	+	+	–	+	–	–	–	–	–	+	+	–	–	+
Mollusca															
Polyplacophora															
Ischnochiton subviridis Iredale & May	25	–	–	–	–	–	–	–	–	–	+	–	–	–	–
I. variegatus (Adams & Angus)	26	–	–	–	–	–	–	–	+	+	–	–	–	–	–
I. australis (Sowerby)	27	–	–	–	–	–	–	–	+	–	+	–	–	–	–
I. resplendens Bednall & Mathews	28	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Plaxiphora albida Blainville	29	–	+	–	–	–	–	–	–	–	–	+	–	–	–
Haploplax mayi Pilsbry	30	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Gastropoda															
Unident. opisthobranchian sp.	59	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Tugali cicatricosa Adams	31	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Patelloida insignis (Menke)	32	–	+	–	–	–	–	–	–	–	–	–	–	–	–
P. victoriana (Singleton)	33	–	–	–	+	–	–	–	–	+	–	–	+	+	+
P. alticostata (Angas)	34	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Notoacmea flammea (Quoy & Gaimard)	35	–	–	–	–	–	+	–	–	–	–	–	–	–	–
N. corrodenda (May)	36	–	–	–	–	–	–	–	–	–	–	–	+	–	+
N. petterdi (Tenison Woods)	37	–	+	–	–	–	–	–	–	–	–	+	–	–	+
Lepsiella vinosa (Lamarck)	38	–	–	–	–	–	+	–	–	–	–	–	+	–	–
Thais textilosa (Lamarck)	39	+	+	+	–	–	–	–	–	–	–	+	+	+	+

Phylum* / Class / Species†	Species code	Site code‡ 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Litozamia brazieri (Tenison Woods)	40	+	–	+	–	–	–	–	–	–	–	–	–	–	–
Micrastraea aurea (Jonas)	41	+	–	–	–	–	–	–	–	–	+	–	–	–	–
Turbo undulatus Solander	42	+	–	–	–	–	–	–	+	–	–	–	–	–	–
Phasianella australis (Gmelin)	43	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Austrocochlea constricta (Lamarck)	44	–	–	–	–	–	+	–	+	–	–	–	–	–	–
A. odontis (Wood)	45	–	–	–	–	–	–	–	–	–	+	–	+	–	–
Phasionotrochus irisodontes (Quoy & Gaimard)	46	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Clanculus limbatus (Quoy & Gaimard)	47	–	–	–	–	–	–	–	–	–	+	–	–	–	–
C. plebejus (Philippi)	48	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Melarapha unifasciata (Goray)	49	–	–	–	–	–	–	–	+	–	–	+	–	–	–
Cominella lineolata (Lamarck)	50	–	–	–	–	–	+	–	+	–	+	–	–	–	–
Dentimitrella pulla (Gaskoin)	51	–	–	+	–	–	–	–	–	–	–	–	–	–	–
D. vineta	52	–	–	–	–	–	–	–	–	–	+	–	–	–	–
D. tayloriana	53	–	–	–	–	–	–	–	–	–	+	–	–	–	–
D. sp.	54	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Bivalvia															
Lasaea australis (Lamarck)	66	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Mytilus edulis planulatus (Lamarck)	56	–	+	–	–	–	+	+	+	–	–	+	–	–	+
Austromytilus rostratus (Dunker)	57	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Chlamys asperrimus (Lamarck)	58	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Bryozoa															
Gymnolaemata															
Emma triangula Haastings§	15	–	–	+	–	+	–	–	–	–	+	+	–	–	+
Rhabdozoum wilsoni Hincks§	16	–	–	–	–	+	–	–	–	–	+	–	–	–	–
Cellaria sp.§	17	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Electra pilosa (L.)§	18	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Membranipora sp.§	19	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Unident. bryozoan sp.A§	20	–	–	–	–	–	–	–	–	–	+	–	–	–	–
Unident. bryozoan sp.B§	21	–	–	–	–	+	–	–	–	+	+	–	–	–	–
Echinodermata															
Stelleroidea															
Patiriella vivipara Dartnall	01	–	–	–	–	–	–	–	–	–	–	+	–	–	–
P. calcar Lamarck	02	–	–	+	–	–	–	–	–	–	–	+	–	–	–
Tosia magnifica (Muller & Troschel)	03	–	–	–	+	–	–	–	–	–	+	–	–	–	–
Paranepanthia grandis Clark	04	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Chordata															
Pisces															
Unident. clingfish	61	–	–	–	+	–	–	–	–	–	–	–	–	–	–

The following Crustacea were also found: *Isychromene* sp. A and B ¶, *Dynamenopsis* sp. ¶, *Cymodoce coronata* (Leach) ¶, *Euidotea peronii* Milne Edwards ¶, *Crabysoz elongatus* (Miers) ¶, Pontogeneidae Genus A sp.A ¶, Podoceridae Genus A sp.A ¶

* Classification of invertebrates follows George & George (1979).

† Nomenclature follows identification guides cited in text and hence may exclude some recent unpublished revisions.

‡ See table 1.

§ Epiphytic species.

¶ Free-living species found among fronds of *Xiphophora*.

TABLE 4

The Constancy and Fidelity of the Algal Species Groups to the Site Groups

Site group	Species group* 1	2	3	4	5	6	7	8	9
Constancy									
A	0.33	0.67	0	0.11	0.25	0	0.06	0.10	0
B	0	0.20	0	0	0	0	0.17	0	0
C	0	0	0.17	0	0.75	0	0.04	0	0.25
D	0	0.07	0.22	0.33	0.17	0.17	0.36	0.08	0.08
E	0	0	0	0.33	0	0	0	0.14	0.50
Fidelity									
A	5.00	3.53	0	0.73	1.09	0	0.46	1.67	0
B	0	1.05	0	0	0	0	1.31	0	0
C	0	0	2.13	0	3.26	0	0.31	0	1.67
D	0	0.37	2.75	2.20	0.74	5.00	2.77	1.33	0.53
E	0	0	0	2.20	0	0	0	2.33	3.33

* From figure 3.

TABLE 5

The Constancy and Fidelity of the Faunal Species Groups to the Site Groups

Site Group	Species group* 1	2	3	4	5	6	7	8	9	10	11
Constancy											
A	0	0.05	0.88	0.13	0.19	0	0.25	0.03	0.05	0.19	0
B	0	0	0.50	0	0.25	0	0	0	0	0	1.00
C	0	0	0.25	0	0.13	0.13	0	0.13	0.60	0	0
D	0	0	0	0	0.38	0.63	0	0	0.03	0.38	0
E	0.36	0.33	0.17	0.33	0.83	0.08	0	0	0.03	0	0
F	0	0.10	0.25	0	0.63	0	0.25	0.56	0.08	0.13	0
Fidelity											
A	0	0.63	2.59	1.69	0.47	0	3.13	0.25	0.38	1.62	0
B	0	0	1.47	0	0.63	0	0	0	0	0	5.89
C	0	0	0.74	0	0.33	0.93	0	1.00	4.62	0	0
D	0	0	0	0	0.95	4.50	0	0	0.23	3.25	0
E	6.00	4.13	0.50	4.29	2.08	0.57	0	0	0.23	0	0
F	0	1.25	0.74	0	1.58	0	3.13	4.31	0.62	1.11	0

* From figure 3.

GENERAL DISCUSSION AND CONCLUSIONS

This work has identified a number of algal and animal species that are characteristic of the *Xiphophora* subzone in various areas around Tasmania. These lists are the only description yet available of the assemblage within which *Xiphophora* lives, as distinct from the wider sublittoral fringe zone. A knowledge of the community composition of this subzone is a necessary prelude to understanding the ecological interactions which drive this system. This study has also examined the patterns of variation within the assemblage and suggested some factors which may control that variation. Both animal and plant species compositions are strongly correlated to wave exposure and, to a lesser extent, to freshwater run-off (in the form of the tannin-stained waters of Port Davey and the less-stained but perhaps more brackish waters from the Huon River). Both groups of organisms also show some inter-regional variations in species composition, though these are not consistent. Amongst the algae, the southwestern area is particularly distinct, while some aspects of floral composition distinguish the northeastern or D'Entrecasteaux Channel sites from other areas. The faunal assemblages differ between all regions but that in the D'Entrecasteaux Channel is particularly distinct.

One of the most prominent results of these analyses is the relative ecological peculiarity of the *Xiphophora* subzone in the D'Entrecasteaux Channel. This is presumably partly as a result of shelter and the influence of Huon River water. It may also relate to the absence in that region of *Durvillaea* and other competitive dominants of the sublittoral fringe zone, an absence which permits *Xiphophora* to expand into a major belt from the extreme low tide line down to one or two metres depth below Lowest Astronomic Tide. This expansion may allow the *Xiphophora* subzone to encompass parts of the ranges of various sublittoral species. Equally, *Xiphophora* does not grow above low tide mark in this region, a situation which will again tend to alter the species occurring in its subzone. However, none of these reasons seems sufficient to account fully for the marked difference in species composition, particularly of animals, of the channel sites. Part of the uniqueness of these D'Entrecasteaux Channel species compositions involves the prominent occurrence there of an epifauna on *Xiphophora* and, to a less marked extent, of an epiflora. D'Antonio (1985) has shown that macroalgal epiphytes are a significant food source for foraging herbivores. The algal epiphytes, which were often concentrated at the base of the plants or in spent conceptacles (cf. Russell & Veltkamp 1984), may therefore attract and support the gastropods and other animals found uniquely in the region. The reason for the predominance of epiphytes nevertheless remains obscure. Epifloral macroalgae, as a group, are widespread, but they tend to be most common in the upper sublittoral zone on exposed shores (Womersley 1981), in marked contrast to the pattern reported here.

In terms of the lists of species found living with *Xiphophora*, this study has shown the subzone to have high species richness, in contrast to the conclusions of earlier workers concerning the sublittoral fringe zone as a whole. Much of this increased richness stems from the presence in the *Xiphophora* subzone of species which Bennett & Pope (1960) and Edgar (1984) allocated to the floras and faunas of other zones. Most of these are supposed eulittoral species whose ranges are now seen to extend into at least the upper margin of the sublittoral fringe. Fewer sublittoral species extend up through the fringe zone to be found with *Xiphophora*. The present work has shown that, on Tasmanian shores, the lower eulittoral and sublittoral fringe zones, as defined by their biota, grade into one another.

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REFERENCES

ALVEY, N.G., BANFIELD, C.F., BAXTER, R.I., GOWER, J.C., KRZANOWSKI, W.J., LANE, P.W., LEECH, P.K., NELDER, J.A., PAYNE, R.W., PHELPS, K.M., ROGERS, C.E., ROSS, G.J.S., SIMPSON, H.R., TODD, A.D., WEDDERBURN, R.W.M. & WILKINSON, G.N., 1977: *GENSTAT. A GENERAL STATISTICAL PROGRAM*. Rothamsted Experimental Station, Harpenden, Hertfordshire.

BAARDSETH, E., 1970: A square-scanning, two-stage sampling method of estimating seaweed quantities. *Norw. Inst. Seaweed Res.* Rep. 33: 41 pp.

BENNETT, I. & POPE, E.C., 1960: Intertidal zonation of the exposed rocky shores of Tasmania and its relationships with the rest of Australial. *Aust. J. Mar. Freshw. Res.* 11: 182–221.

BOLD, H.C. & WYNNE, M.J., 1978: *INTRODUCTION TO THE ALGAE*. Prentice-Hall, New Jersey.

CLIFFORD, H.T. & STEPHENSON, W., 1975: *AN INTRODUCTION TO NUMERICAL CLASSIFICATION*. Academic Press, New York.

COLVOCORESSES, J.A. & MUSICK, J.A., 1984: Species associations and community composition of middle Atlantic Bight continental shelf demersal fishes. *Fish. Bull.* 82: 295–313.

COTTON, B.A., 1964: *SOUTH AUSTRALIAN MOLLUSCA: CHITONS*. Government Printer, South Australia.

CRIBB, A.B., 1954: The algal vegetation of Port Arthur, Tasmania. *Pap. Proc. R. Soc. Tasm.* 88: 1–44.

D'ANTONIO, C., 1985: Epiphytes on the rocky intertidal red alga *Rhodemela larix* (Turner) C.Agardh: negative effects on the host and food for herbivores. *J. Exp. Mar. Biol. Ecol.* 86: 197–218.

DARTNALL, A., 1980. *TASMANIAN ECHINODERMS*. Fauna of Tasmania Handbook No.3. University of Tasmania Press.

DICE, L.R., 1945: Measures of the amount of ecologic association between species. *Ecology* 26: 297–302.

DIXON, P., 1958: The structure and development of the thallus in the British species of *Gelidium* and *Pterocladia*. *Ann. Bot.* 22: 353–368.

EDGAR, G.J., 1983a: The ecology of south-east Tasmanian phytal animal communities. I. Spatial organization on a local scale. *J. Exp. Mar. Biol. Ecol.* 70: 129–157.

EDGAR, G.J., 1983b: The ecology of south-east Tasmanian phytal animal communities. II. Seasonal change in plant and animal populations. *J. Exp. Mar. Biol. Ecol.* 70: 159–179.

EDGAR, G.J., 1983c: The ecology of south-east Tasmanian phytal animal communities. III. Patterns of species diversity. *J. Exp. Mar. Biol. Ecol.* 70: 181–203.

EDGAR, G.J., 1984: General features of the ecology and biogeography of Tasmanian subtidal rocky shore communities. *Pap. Proc. R. Soc. Tasm.* 118: 173–186.

FAITH, D.P., MINCHIN, P. & BELBIN, L., 1987: Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69: 57–68.

FRITSCH, F.E., 1935: *THE STRUCTURE AND REPRODUCTION OF THE ALGAE, VOLUME 1*. Cambridge University Press, Cambridge.

FRITSCH, F.E., 1945: *THE STRUCTURE AND REPRODUCTION OF THE ALGAE, VOLUME 2*. Cambridge University Press, Cambridge.

FUHRER, B., CHRISTIANSON, I.G., CLAYTON, M.N. & ALLENDER, B.M., 1981: *SEAWEEDS OF AUSTRALIA*. A.H. & A.W. Reed Pty Ltd, Sydney.

GEORGE, J.D. & GEORGE, J.J., 1979: *MARINE LIFE. AN ILLUSTRATED ENCYCLOPEDIA OF INVERTEBRATES IN THE SEA*. Harrap, London.

GOWER, J.C., 1966: Some distance properties of latent root and vector methods used in multivariate analysis. *Biometrika* 53: 325–338.

GUILER, E.R., 1952a: The intertidal ecology of the Eaglehawk Neck area. *Pap. Proc. R. Soc. Tasm.* 86: 13–29.

GUILER, E.R., 1952b: The marine algae of Tasmania: checklist with localities. *Pap. Proc. R. Soc. Tasm.* 86: 71–106.

GUILER, E.R., 1954: The intertidal zonation at two places in southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 88: 105–118.

GUILER, E.R., SERVENTY, D.L. & WILLIS, E.H., 1958: The Fisher Island Field Station — with an account of its principal fauna and flora. *Pap. Proc. R. Soc. Tasm.* 92: 165–183.

HALE, H.M., 1927: *THE CRUSTACEANS OF SOUTH AUSTRALIA. PART I*. Handbooks of the Flora and Fauna of South Australia. Government Printer, South Australia.

HALE, H.M., 1929: *THE CRUSTACEANS OF SOUTH AUSTRALIA. PART II*. Handbooks of the Flora and Fauna of South Australia. Government Printer, South Australia.

JOHANSEN, H.W. & WOMERSLEY, H.B.S., 1986: *Haliptilon roseum* (Corallinaceae, Rhodophyta) in southern Australia. *Aust. J. Bot.* 34: 551–567.

KAAS, P. & VAN BELLE, R.A., 1980: *CATALOGUE OF LIVING CHITONS (MOLLUSCA: POLYPLACOPHORA)*. Dr W. Backhuys Publ., Rotterdam.

KING, R.J., 1973: The distribution and zonation of intertidal organisms in Bass Strait. *Proc. R. Soc. Vict.* 85: 145–163.

LEGENDRE, L. & LEGENDRE, P., 1983: *NUMERICAL ECOLOGY. DEVELOPMENTS IN ENVIRONMENTAL MODELLING 3*. Elsevier Scientific Publ. Co., New York.

MACPHERSON, J.H. & GABRIEL, C.J., 1962: *MARINE MOLLUSCS OF VICTORIA*. Melbourne University Press, Melbourne.

MARINE RESEARCH GROUP OF VICTORIA, 1984: *COASTAL INVERTEBRATES OF VICTORIA. AN ATLAS OF SELECTED SPECIES*. Harston, Partridge & Co. Pty Ltd, Richmond, Victoria.

MAY, W.L. & MACPHERSON, J.H., 1958: *AN ILLUSTRATED INDEX OF TASMANIAN SHELLS*. Government Printer, Tasmania.

PHILLIPS, J.A., 1984: The validity of morphological and anatomical characters in distinguishing species of *Ulva* in southern Australia. *In* Irvine, D.E.G. & John, D.M. (Eds): *SYSTEMATICS OF THE GREEN ALGAE*. Systematics Association Special Volume 27.

PONDER, W.F. & CREESE, R.G., 1980: A revision of the Australian species of *Notoacmea*, *Collisella* and *Patelloida* (Mollusca:Gastropoda:Acmaeidae). *J. Malacol. Soc. Aust.* 4: 167–208.

RICE, E.L., 1989: A statistical morphological analysis and taxonomic revision of the genus *Xiphophora* (Fucaceae). *Bot. J. Linn. Soc.* in press.

RICE KENCHINGTON, E.L., 1987: Geographic, morphological and genetic variation in *Xiphophora gladiata*. Unpubl. Ph.D. thesis, Univ. Tasm.

RUSSELL, G. & VELTKAMP, C.J., 1984: Epiphyte survival on skin-shedding macrophytes. *Mar. Ecol. Prog. Ser.* 18: 149–153.

SAENGER, P., 1974: Natural history of the Hogan Group 2. Some marine algae from Hogan Island, Bass Strait, with an account of the marine zonation. *Pap. Proc. R. Soc. Tasm.* 107: 73–81.

SAITO, Y. & WOMERSLEY, H.B.S., 1974: The southern Australian species of *Laurencia* (Ceramiales: Rhodophyta). *Aust. J. Bot.* 22: 815–874.

SHEPHERD, S.A. & THOMAS, I.M., 1982: *MARINE INVERTEBRATES OF SOUTHERN AUSTRALIA. PART 1*. Government Printer, South Australia.

SNEATH, P.H.A. & SOKAL, R.R., 1973: *NUMERICAL TAXONOMY*. Freeman, San Francisco.

SPSS INC., 1986: *SPSS^x USER'S GUIDE. SECOND EDITION*. McGraw-Hill Book Co., New York.

UNDERWOOD, A.J., 1981: Structure of a rocky intertidal community in New South Wales: Patterns of vertical distribution and seasonal changes. *J. Exp. Mar. Biol. Ecol.* 51: 57–85.

WESTCOTT, G., 1976: The intertidal crabs of Victoria. *Vict. Nat.* 93: 237–245.

WOMERSLEY, H.B.S., 1964: The morphology and taxonomy of *Cystophora* and related genera (Phaeophyta). *Aust. J. Bot.* 12: 53–110.

WOMERSLEY, H.B.S., 1967: A critical survey of the marine algae of Southern Australia II. Phaeophyta. *Aust. J. Bot.* 15: 189–270.

WOMERSLEY, H.B.S., 1981: Marine ecology and zonation of temperate coasts. *In* Clayton, M.N. & King, R.J. (Eds): *MARINE BOTANY: AN AUSTRALIAN PERSPECTIVE*. Longman Cheshire Pty Ltd, Melbourne.

WOMERSLEY, H.B.S., 1984: *THE MARINE BENTHIC FLORA OF SOUTHERN AUSTRALIA. PART I. HANDBOOK OF THE FLORA AND FAUNA OF SOUTH AUSTRALIA*. Government Printer, South Australia.

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PHENOLOGY AND GERMINATION IN SOME RAINFOREST CANOPY SPECIES AT MT FIELD NATIONAL PARK, TASMANIA

by Jennifer Read

(with five tables and three text-figures)

READ, J., 1989 (31:x): Phenology and germination in some rainforest canopy species at Mt Field National Park, Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 211–221. ISSN 0080–4703. Botany Department, University of Adelaide, GPO Box 498, Adelaide, South Australia 5001; formerly Botany Department, University of Tasmania.

The timing of shoot expansion, flowering, germination and leaf fall was recorded in some rainforest canopy species at Mt Field National Park, Tasmania. Seed collected from these and two other species was germinated in Hobart under controlled conditions. Most of the variation in phenology and germination requirements was continuous and correlated broadly with distribution with respect to the temperature climate. The species which commonly occur at high altitudes — *Athrotaxis selaginoides*, *A. cupressoides*, *Nothofagus gunnii* and *N. cunninghamii* — germinated earlier at low temperatures than the others, with provenance variation indicated in *N. cunninghamii*. The cold-sensitive species *Atherosperma moschatum* failed to germinate at low temperatures, with a secondary dormancy indicated. *Atherosperma moschatum* and *Phyllocladus aspleniifolius* showed delayed shoot expansion during the cool growing season of 1984–85 which rendered the shoots more frost-sensitive. The periodicity of seed production is also greatest in the high altitude species, although the ecological implications are uncertain with respect to climate. Only *P. aspleniifolius* shows evidence of prolonged seed dormancy. This characteristic enables the populations to survive large-scale disturbance as soil-stored seed and therefore is an important feature of the regeneration ecology of this species.
Key Words: germination, phenology, *Atherosperma*, *Athrotaxis*, *Eucryphia*, *Nothofagus*, *Phyllocladus*, Tasmania.

INTRODUCTION

Although rainforest forms one of the major vegetation types in Tasmania, relatively little of the basic biology of the component species is documented, other than autecological studies of *Nothofagus cunninghamii* (Hook.) Oerst. (Howard 1973a,b,c) and a study of germination and dispersal in *N. cunninghamii*, *Eucryphia lucida* (Labill.) Baill. and *Atherosperma moschatum* Labill. (Hickey *et al.* 1983). Read & Hill (1985, 1988a) have described regeneration patterns in the major canopy species, *N. cunninghamii*, *A. moschatum*, *E. lucida*, *Athrotaxis selaginoides* D. Don and *Phyllocladus aspleniifolius* (Labill.) Hook. f. They noted differences among the species in their gap requirement for regeneration and modes of reproduction which have a large impact on the forest dynamics and community composition. The large gap requirement of *P. aspleniifolius* and *A. selaginoides* is of particular interest, since regeneration in closed forests by these species is commonly insufficient to maintain their continued presence in such forests, although they may currently form a major component of the forest canopy (Ogden 1978, Cullen 1987a,b, Read & Hill 1988a). Similar population dynamics have been recorded in *Athrotaxis cupressoides* D. Don (Ogden 1978) and *Nothofagus gunnii* (Hook. f.) Oerst. (Read & Hill 1988a, unpubl. data). The occurrence of these species with respect to altitude and climate, summarised in table 1, has been discussed by Read & Hill (1988b) and Cullen (1987a,b).

Temperate trees have a limited growing season in natural conditions and there is considerable variation among species in the timing and patterns of foliage expansion and the timing of flowering and seed release (e.g. Wareing 1956, Bussell 1968). Variation may also occur within a single species at different sites. Similarly, the importance of the relationships between the physical environment and seed germination in the distribution of a species in space and time, and the variability of these relationships has been noted by many authors (e.g. Grubb 1977, Bazzaz 1979). These features are examined in *Nothofagus cunninghamii*, *Eucryphia lucida*, *Atherosperma moschatum*, *Phyllocladus aspleniifolius* and *Athrotaxis selaginoides* at Mt Field National Park (42°41'S, 146°40'E), with experimental germination studies on seed collected from these species, as well as from *Nothofagus gunnii* and *Athrotaxis cupressoides*, in order to determine whether differences among species in phenology and germination characteristics may

TABLE 1

Summary of the Distribution of some Rainforest Canopy Species with Respect to Altitude in Tasmania

Species	Altitudinal occurrence	
	Range (m a.s.l.)	% of records over 800 m a.s.l.*
Atherosperma moschatum	0–1120	12
Athrotaxis cupressoides	600–1330	93
A. selaginoides	20–1300	56
Eucryphia lucida	0–1000	3
Nothofagus cunninghamii	0–1260	27
N. gunnii	550–1260	88
Phyllocladus aspleniifolius	0–1160	25

* The percentages refer to records from surveys and herbarium collections (data supplied by M.J. Brown, J.R. Busby and the Tasmanian Herbarium), and do not necessarily reflect stem frequency over these altitudes.

TABLE 2

Species, Site Locations and Phenological Features recorded at Mt Field National Park

Altitude (m a.s.l.)	Species	Observations
180	*Atherosperma moschatum* *Nothofagus cunninghamii*	Leaf expansion: 1982–83, observations fortnightly
700	*A. moschatum* *Eucryphia lucida* *N. cunninghamii* *Phyllocladus aspleniifolius*	Leaf expansion: 1982–83, observations fortnightly. Flowering*, seeding and germination: 1982, 1984 and 1985, observations monthly, but with some gaps in the observation period.
920	*A. moschatum* *Athrotaxis selaginoides* *N. cunninghamii* *P. aspleniifolius*	Leaf expansion: 1982–83, observations fortnightly. Flowering*, seeding and germination: 1982, 1984 and 1985, observations monthly with some gaps in the observation period.
980	*A. selaginoides* *N. cunninghamii*	Leaf expansion: 1982–83, observations fortnightly.

* The presence/absence of flowering was noted annually from 1982–88.

contribute to the observed patterns of species regeneration and distribution.

METHODS

Phenology

Four sites were selected at Mt Field over an altitudinal range of 800 m, from 180 m a.s.l. to 980 m a.s.l. The species observed at each site and the features recorded are listed in table 2. Sites 1–4 were observed from May 1982 to May 1983 at fortnightly intervals. Sites 2 and 3 were also observed from August 1984 to August 1985 at monthly intervals. At each site, five lateral branches were tagged on three trees of each species on exposed forest edges. Saplings (originated from seed) of *Nothofagus cunninghamii*, *Eucryphia lucida* and *Phyllocladus aspleniifolius* were also tagged at Site 2. No saplings of seedling origin were found in *Atherosperma moschatum* at this site. The following features were recorded:

(1) the timing of bud-break;
(2) leaf production and abscission;
(3) the time of flowering, seeding and germination (where possible); germination is often difficult to record directly in the field, and here is recorded indirectly as the first appearance of cotyledonary seedlings.

Growth patterns were also observed fortnightly from 1982 to 1985 in seedlings raised in Hobart from seed or cotyledonary seedlings collected from Mt Field in June 1982. One group of five seedlings of each species was grown outside under natural daylengths, and another group of seedlings was grown in a glasshouse under natural daylengths.

Germination

Seed was collected from Mt Field in 1982, a year of exceptionally high seed production for all of these species, from three trees each of *Nothofagus cunninghamii* (Nc700), *Eucryphia lucida*, *Phyllocladus aspleniifolius* and *Atherosperma moschatum* at 700 m a.s.l. and from *N. cunninghamii* (Nc980), *N. gunnii*, *Athrotaxis selaginoides* and *A. cupressoides* at 980 m a.s.l. All seeds were collected and sown in 1982 following dry storage at room temperature. Poorly developed seeds of *A. moschatum* and *Athrotaxis* spp. were discarded, and therefore the final germination percentages do not reflect the overall viability of the seed crop.

The seed treatments for each species were as follows:

(1) incubated moist in light at 4°, 12°, 17°, 25° and 32°C;
(2) incubated moist in dark conditions at 25°C;
(3) incubated moist in light at 4°C for four weeks, followed by 25°C.

The failure of *Phyllocladus aspleniifolius* to germinate in any of the above treatments led to the following treatments for this species only:

(4) seed soaked for 24 hours in HCl (pH 2) followed by incubation moist in light at 20°C;
(5) seed scarified and incubated moist in light at 20°C;
(6) seed coat removed and seed incubated moist in light at 20°C;
(7) seed boiled for 5 minutes then incubated moist in light at 20°C;
(8) seed sown in pots of sandy loam and placed outside in full sunlight, with daily watering.

In treatments 1 to 7, 30–40 seeds of each tree were placed in a petri dish on a pad of Whatman's Seed Test Thick filter paper (three dishes per species for each treatment, one for each parent tree). "Thiram" fungicide was dusted on the seed pad prior to the addition of distilled water. The petri dishes were incubated in controlled environment growth cabinets under incandescent and fluorescent lights (150 µmol quanta $m^{-2}s^{-1}$). The "dark" treatment was provided by cardboard boxes lined with black cartridge paper and seeds placed in this treatment were sown and observed under green light.

Results were observed every 1–2 days for the first 50 days, then every 3–5 days until Day 100, followed by irregular observations. Observations of treatments 1–3 were continued for 25 days after the last seed germinated. Observations of the 12°C treatment ceased after 125 days, due to fungal infection of the remaining seeds. Observations of treatments 4–7 were discontinued after 90 days. Treatment 8 was observed for 30 months.

RESULTS

Bud-break and Shoot Expansion

The uppermost bud on *Nothofagus cunninghamii* shoots is lateral rather than apical, with the new branch rotating to appear apical (Howard 1973b). The overwintering buds are sheathed by bracts, whereas in *Eucryphia lucida* the buds are enclosed in a yellow wax. Apical buds of the other

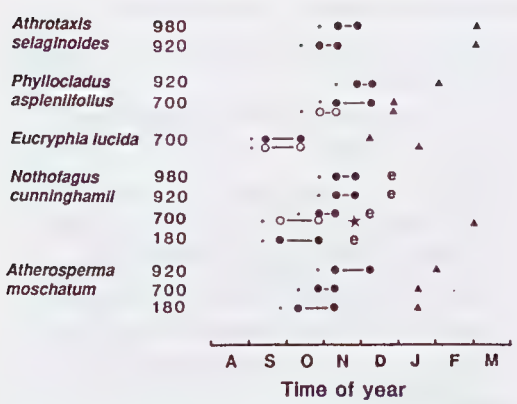

FIG. 1 — Timing of leaf production at Mt Field at each altitude, examined at two-week intervals in 1982–83.

●—● *The period during which bud-break occurred in mature plants*

○—○ *The period during which bud-break occurred in saplings (of seedling origin) 1–1.5 m high.*

The dots (•) preceding the marked period indicate the time of the previous observation. Most Nothofagus cunninghamii *leaves were produced during the spring growth flush, but some expanded shoots of saplings continued to produce new leaves at the apices.*

e *The date at which* N. cunninghamii *leaves were fully expanded.*

✱ *The date at which* N. cunninghamii *leaves produced in the spring growth flush were fully expanded, with further leaf production occurring at the shoot apices or in later growth flush.*

▲ *The date by which leaf production had ceased.*

species are protected to some extent by the infolding of older leaves, and in *Phyllocladus aspleniifolius* by bud scales.

Bud-break occurred later with increasing altitude in all species except in *Nothofagus cunninghamii* at 920 m and 980 m (fig. 1). There was no distinct pattern in the timing of bud-break among species, other than the later bud-break of *Phyllocladus aspleniifolius* compared with other species. At 180 m a.s.l. *N. cunninghamii* buds broke earlier than those of *Atherosperma moschatum*, but there was no difference in timing between these species at 700 m a.s.l. and 920 m a.s.l. Similarly, *Athrotaxis selaginoides* buds opened earlier than those of *N. cunninghamii* at 920 m a.s.l. but there was no difference among these species at 980 m a.s.l. Bud-break occurred up to 2–4 weeks earlier in saplings of *P. aspleniifolius* and *N. cunninghamii* at 700 m a.s.l. than in adults. In 1984, bud-break was delayed in *A. moschatum* and *P. aspleniifolius*, so that at the 920 m a.s.l. site, leaves of these species were not fully expanded and hardened by June 1985 (Read & Hill 1988b). In contrast, leaves of the other species were fully expanded and hardened by late summer–early autumn (Read & Hill 1988b).

Nothofagus cunninghamii shoots from saplings and mature plants showed predominantly determinate growth, with a single flush of growth from axillary buds during the spring, bearing 5–16 leaves. This growth pattern is similar to that described in detail by Howard (1973b) in *N. cunninghamii* in Victoria. Many terminal axillary buds remained dormant for the whole observation period. Axillary buds formed during the growth flush occasionally broke dormancy in saplings at 180 m a.s.l. and 700 m a.s.l. during the late summer to form a second growth flush; occasional sapling shoots produced leaves continuously. Determinate shoots were fully expanded within 4–6 weeks at all sites and leaves were fully expanded within 6–8 weeks (fig. 1). *N. cunninghamii* seedlings which had germinated in Hobart in June 1982 showed continuous apical growth in the glasshouse during winter, and axillary buds broke in August. Seedlings growing outside in August showed some apical growth through winter, with axillary buds breaking in October. Subsequent growth in seedlings, both inside and outside the glasshouse, was a combination of growth flushes from axillary buds and continuous apical growth until early autumn. Growth then ceased outside the glasshouse but continued inside the glasshouse, both by continuous apical growth and occasional flushes from dormant axillary buds, with a major period of determinate growth soon after daylength began increasing in winter. This pattern of growth, with slight variations in timing from year to year, was observed in the same seedlings until observations ceased in October 1985.

All other species produced foliage indeterminately. *Atherosperma moschatum* and *Eucryphia lucida* usually produced 2–4 leaves on each shoot during the growing season at Mt Field. *Phyllocladus aspleniifolius* usually produced a single whorl of 5–7 phylloclades (mostly determinate). The *Athrotaxis selaginoides* shoots produced 11–23 leaves. Leaf production in mature plants of *A. selaginoides*, *A. moschatum*, *E. lucida* and *P. aspleniifolius* ceased during summer and

did not resume until the following spring. Leaf production ceased later at the higher altitudes (fig. 1). In seedlings raised in Hobart, leaf production was continuous in the glasshouse, and continued very slowly outside the glasshouse during the first winter after germination. In later years, growth continued until May outside the glasshouse, then did not resume until October. These growth patterns remained constant until observations ceased in October 1985, with slight variation in timing from year to year.

The foliage of *Phyllocladus aspleniifolius* seedlings at Mt Field consisted entirely of leaves for the first two to three years of growth, but seedlings of the same age which were grown outdoors in Hobart (with a faster growth rate) produced phylloclades within six months.

No leaf loss was recorded in any of these species other than due to browsing. Therefore the leaf life span was greater than 41 months.

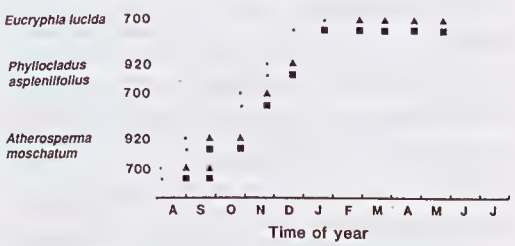

FIG. 2 — Timing of flowering at Mt Field at each altitude, examined at monthly intervals in 1983–84 (■) and 1984–85 (▲). Flowering was not observed in A. selaginoides *and* Nothofagus cunninghamii *during this period. The dots (•) preceding the marked period indicate the date of the preceding observation. The date shown for* Phyllocladus aspleniifolius *indicates only the first appearance of the cones. The dates shown for both* P. aspleniifolius *and* Atherosperma moschatum *refer only to the appearance of female cones/flowers.*

Flowering, Seeding and Germination at Mt Field

In 1984–85, flowering and seed maturation of *Eucryphia lucida* were delayed (figs 2 & 3). Seed maturation and germination were also delayed in *Atherosperma moschatum* in 1984–85, and flowering in this species was delayed in 1985 (figs 2 & 3). These delays coincided with the slightly lower temperatures of the 1984–85 growing season. Bureau of Meteorology records at Maydena (42°46'S, 146°36'E, 267 m a.s.l.) show mean monthly temperatures from November to February averaging 20.4°C in 1983–84, compared with 19.4°C in 1984–85. The timing of cone development in *Phyllocladus aspleniifolius* was not delayed but seed maturation at 920 m a.s.l. was late (fig. 3). The flowering period of *E. lucida* is long relative to that of *A. moschatum* (fig. 2). However, the pollination period may be narrowed by the behaviour of the insect pollinators.

Flowering and seeding of *Nothofagus cunninghamii* and *Athrotaxis selaginoides* at Mt Field were recorded only in the 1981–82 growing season, which was a season of prolific seed production for all the species in this study. Occasional empty cupules of *N. cunninghamii* were observed in subsequent years, indicating that flowering was occurring in this species at a very low frequency. No viable seeds were found. However, cone development was recorded in *Athrotaxis* species in late September 1988, and also

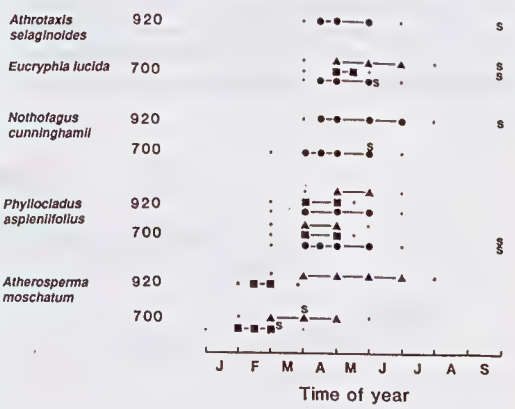

FIG. 3 — Timing of the period of seed maturation and release (● 1982; ■ 1984; ▲ 1985), and the first appearance of seedlings (s) at Mt Field at each study site, examined at two- or four-week intervals. The dots (•) indicate the dates of observations prior to seed maturation and following the majority of seed release.

heavy flowering of *N. cunninghamii* and *N. gunnii* in October and November respectively, with indications of a year of heavy seeding for both genera. *Atherosperma moschatum* and *Eucryphia lucida* flowered prolifically each year and *Phyllocladus aspleniifolius* produced cones each year, but most prolifically in the 1981–82 growth season and again in 1988–89.

Germination of *Nothofagus cunninghamii* was recorded during autumn at 180 m a.s.l. and 700 m a.s.l. in 1982, with seedlings not apparent until spring at 920 m a.s.l. and 980 m a.s.l. (fig. 3). *Athrotaxis selaginoides* seedlings did not appear until spring in 1982. *Eucryphia lucida* was only studied at 700 m a.s.l. at Mt Field, with autumn germination recorded in 1982 and spring germination in 1984 and 1985. *E. lucida* seed does not mature until the autumn following the year of flowering. *Atherosperma moschatum* seedlings appeared in autumn at 180 m a.s.l. and 700 m a.s.l. At 920 m a.s.l. seeding was profuse, and seed collected in March 1985 was germinated in the laboratory with 92% viability of well-formed seed, which was equivalent to 36% of the total seed collected. However, successful field germination of *A. moschatum* was very rare at this site. Many hundreds of well-formed seeds were observed close to the parent trees, but only two cotyledonary seedlings were recorded, germinating in September. Although many seeds remained intact after winter, no further germination was observed. Cotyledonary seedlings of *Phyllocladus aspleniifolius* appeared in spring at 700 m a.s.l. The seed crop of *P. aspleniifolius* at 920 m a.s.l. was small, except in 1982, and no seedlings were observed at this site.

Experimental Germination

Phyllocladus aspleniifolius seed did not germinate under treatments 1–3. The other species germinated readily under these treatment conditions (table 3). The germination score for these species at 25°C was unaffected by the light conditions (table 3). The onset of germination was most rapid and the time taken to reach 50% of the final germination score shortest at 25°C for all species, although with little difference at 17°C (tables 3 & 4). Incubation temperature did not affect the final germination percentage, other than at 32°C, where no germination occurred and seed had deteriorated after 28 days, and at 4°C in *Atherosperma moschatum* (table 3). At 12°C a substantial proportion of seeds of *Nothofagus cunninghamii*, *A. moschatum* and *Eucryphia lucida* were infected by fungus after 125 days (tables 3 &4) and scoring was abandoned. The final germination percentage is assumed to be the same as at 25, 17 and 4°C for *N. cunninghamii* and *E. lucida*. However, since *A. moschatum* failed to germinate at 4°C, the

TABLE 3

Final Germination Percentages of each Species*

Species	Site (m a.s.l.)	Incubation temperature (°C)						
		32	25 light	25 dark	17	12	4	4–25†
Nothofagus cunninghamii	700	0	21	20	22	12‡	24	25
	980	0	48	50	48	26‡	51	46
N. gunnii	980	0	43	40	36	39	41	40
Eucryphia lucida	700	0	93	91	93	60‡	95	93
Atherosperma moschatum§	700	0	92	97	93	49‡	0	99
Athrotaxis selaginoides§	980	0	61	59	63	60	67	63
A. cupressoides§	980	0	51	52	57	57	57	51

* Each percentage value is the mean of results of seed from three trees at the same site.
† 4°C for 4 weeks, then incubated at 25°C.
‡ The final count was at 125 days, with remaining seeds infected by fungus.
§ Poorly formed seeds (small, shrivelled or discoloured) were not included.

reduced germination score of *A. moschatum* at 12°C may be due to factors other than fungal infection. Differences among trees in germination rate were small. Variation in viability ranged from 3% of the mean value in *A. moschatum* to 19% in *N. cunninghamii*.

The 4°C pre-treatment increased the rate of germination for *Eucryphia lucida*, *Nothofagus gunnii* and *Athrotaxis selaginoides* (table 4) but had no effect on the final germination percentage of any species (table 3). *N. gunnii*, *A. selaginoides* and *A. cupressoides* germinated earlier at 4°C than the other species (table 5), including Nc980, and germination of these species was complete within 125 days at 12°C (tables 3 & 4). *N. cunninghamii* seed collected at 980 m a s.l. germinated more rapidly at 12°C and 4°C than seed collected from 700 m a s.l. (tables 4 & 5).

Phyllocladus aspleniifolius failed to germinate in Treatments 1–7, although seeds had fully imbibed water within 24 hours. Observations on Treatment 3 ceased on Day 151 due to fungal attack, and on Day 125 for the other treatments. However, seeds germinated in soil placed in the open air with daily watering (Treatment 8) in the spring of 1983, i.e. after two winters. Seedlings appeared in September and there were no later germinations, with a final germination percentage of 62%.

Seed of *Nothofagus cunninghamii*, *N. gunnii*, *Eucryphia lucida*, *Athrotaxis selaginoides* and *A. cupressoides* stored dry at room temperature germinated with 50–80% viability after 32 months. Seed of *Atherosperma moschatum* could not be germinated at 20°C under a 24-hour photoperiod after two months dry storage at room temperature. Seed of *A. moschatum* stored dry at 4°C was successfully germinated at its original level of viability after four months, but with only 3% germination after five months storage. However, the embryo appeared healthy in both cases of germination failure and seed stored in these conditions germinated (96%) after incubation in darkness at 20°C.

DISCUSSION

Phenology

The patterns of shoot growth in *Nothofagus cunninghamii* are identical to those recorded in Victoria by Howard (1973b), although the appearance of a second growth flush in *N. cunninghamii* appears to be more frequent in Victoria than at Mt Field. Howard noted that the incidence of a second flush decreased with increasing altitude at Mt Donna Buang, and therefore the occasional occurrence of a second growth flush at low altitudes at Mt Field and the absence of this feature at high altitudes probably reflects the cooler

TABLE 4

The Number of Days to the Onset of Germination and to reach 50% of the Final Germination Percentage, expressed as a Range

Species	Site (m a.s.l.)	Incubation temperature (°C)			
		25	17	12	4–25*
Nothofagus cunninghamii	700	7–9	9–11	23–125†	7–10
	980	5–6	7–8	14–115†	4–7
N. gunnii	980	7–9	10–12	14–40	1–7
Eucryphia lucida	700	7–15	12–25	23–115†	1–1
Atherosperma moschatum	700	7–10	11–13	26–70†	9–11
Athrotaxis selaginoides	980	8–15	13–23	20–80	1–8
A. cupressoides	980	8–22	10–24	20–85	5–10

* 4°C for 4 weeks, then incubated at 25°C.

† Final germination percentage is assumed to be the same as at 25°C.

TABLE 5

Cumulative Percentages of Laboratory Germination at 4°C

Species	Site m a.s.l.	Days from sowing				
		129	136	140	151	223
Nothofagus cunninghamii	700	0	0	0	1	24
	980	0	0	0	19	51
N. gunnii	980	24	40			
Eucryphia lucida	700	0	0	0	0	95
Atherosperma moschatum	700	0	0	0	0	
Athrotaxis selaginoides	980	0	9	17	67	
A. cupressoides	980	0	7	16	50	54

growing seasons. The only feature of the timing of bud-break that may be differentially limiting to regeneration and geographic distribution of species is the delaying effect of a cool growing season on the shoot expansion of *Atherosperma moschatum* and *Phyllocladus aspleniifolius*, so that these leaves may be susceptible to frost damage (Read & Hill 1988b).

The periodicity of seedfall in *Nothofagus cunninghamii* and *Athrotaxis selaginoides* has implications for regeneration of these species. Hickey *et al.* (1983) recorded seedfall of *N. cunninghamii*, *Atherosperma moschatum* and *Eucryphia lucida* at two sites in northwestern Tasmania from 1975 to 1981, summarising *N. cunninghamii* seedfall back to 1963. These data, plus data from subsequent years (J. Hickey, pers. comm.), indicate sporadic production of seed in *N. cunninghamii*, with heavy falls in 1967, 1969, 1971, 1975, 1977, 1980, 1982 and 1986 interspersed with years of low or moderate seedfall. They did not find any clear relationship between seed production and the temperature of the preceding growing season, but noted that the pattern of seed production was consistent at several sites around Tasmania. Poor seed production in 1986 at Mt Field, however, may be the result of climatic differences. Periodicity of seeding is a common characteristic of *Nothofagus* throughout its geographic range (Wardle 1984) and may allow a greater proportion of seeds and seedlings to escape predation by herbivores (Ash 1982). The time of flowering and seed release reported by Hickey *et al.* (1983) is, in general, earlier than that recorded at Mt Field and probably reflects the cooler climate at Mt Field. The sporadic nature of seed production of *N. cunninghamii* and *Athrotaxis selaginoides*, also observed in the congenerics *N. gunnii* and *A. cupressoides*, and to a lesser extent in *Phyllocladus aspleniifolius* (J. Hickey, pers. comm.), and the association of low seed viability with the years of low seed production (Howard 1973b, Hickey *et al.* 1983) must have a detrimental effect on the colonisation by these species of sites which are disturbed during periods of low seed production. For example, mixed forest burnt in western Tasmania in 1982 had a high seedling density of *N. cunninghamii* by spring 1982 (Hill & Read 1984). If this fire had burnt after 1982, the *Nothofagus* component of the mature stand developing after the fire would probably be very much lower, due to the absence of seed during the early stage of site colonisation, with site pre-emption by other species, particularly the rapidly-growing sclerophyll species. Similarly in *A. selaginoides*, which is relatively drought sensitive (unpubl. data), establishment depends on the coincidence of a good seed year with moist conditions. The infrequency of seeding in *A. selaginoides* and the drought sensitivity of seedlings must limit its ability to colonise disturbed sites, including canopy gaps, particularly combined with the faster growth rates of other rainforest species and rapid site pre-emption following the disturbance. The greater consistency of seedfall in *Atherosperma moschatum* and *Eucryphia lucida* has been shown quantitatively by Hickey *et al.* (1983). There are no long-term data on seedfall in *A. selaginoides*, and data collected since 1983 on *P. aspleniifolius* in northwestern Tasmania indicate some variability, with alternately poor (< 1 g m^{-2}) and moderate seedfall (J. Hickey, pers. comm.). It is notable that the species with the greatest

periodicity of seed production are those commonly occurring at high altitudes. It is not clear whether this is an evolutionary response to facilitate seedling establishment or to facilitate maximum growth during the short growing seasons, with reproduction only when there is an abundance of assimilate.

The time of field germination within a species, with respect to altitude, is probably related to differences both in the time of seed release and in the time taken for germination to occur, each affected by climate. This appears to be particularly critical in *Atherosperma moschatum*, since observations indicate that the late seed release at 920 m a.s.l. in 1985 led to a very low rate of successful field germination, although this seed was successfully germinated in the laboratory soon after its release. Since observations were made only at monthly intervals, fine-scale differences which have not been detected may exist in the onset of germination among species.

Germination Requirements

The early germination of *Nothofagus gunnii*, *Athrotaxis selaginoides* and *A. cupressoides* that was observed experimentally at low temperatures correlates with the predominantly high altitude distribution of these species. The earlier onset of germination at 12°C and 4°C of seed collected from *N. cunninghamii* at 980 m a.s.l. than of seed collected at 700 m a.s.l. is consistent with this trend. Cotyledonary seedlings of *A. selaginoides*, *A. cupressoides*, *N. gunnii* and *N. cunninghamii* were observed in September 1982 at 980 m a.s.l. at Mt Field (4–5 months after seed release) (tables 4 & 5), but the precise timing of seed release and germination is unknown. A high mortality, due to desiccation, occurred during the following summer, particularly on the more exposed microsites. Early germination may therefore be important in allowing early growth and establishment during a period of low evaporative loss, although early germination may also place the seedlings at risk from frost damage. Howard (1973b) noted that seed of *N. cunninghamii* of lowland populations in Victoria germinated soon after release in autumn, but did not germinate until spring at high altitudes. This pattern would be expected to show some annual variation, according to the timing of seed release as well as the climatic conditions following seed release. The data obtained in the present study indicate that the timing of germination in the field is due to the slow germination at low temperatures rather than any pre-chilling requirement. This feature has been previously reported in *N. cunninghamii* (Howard 1973b). The lack of any requirement for pre-chilling treatment in high altitude species has also been recorded in a study of alpine plants of the USA where only 3 out of 60 species had a chilling requirement (Amen 1966). Sayers & Ward (1966) observed that temperatures resulting in the best germination of alpine species in the USA (20–30°C) were similar to those for species native to lowlands. Similarly, in the present study germination was most rapid at 25°C for all species, with seed of all species killed by incubation at 32°C. However, ecologically significant differences may occur at a finer scale of temperatures than those tested here.

Germination failure at 30–35°C has been reported previously in *Atherosperma moschatum* by Read (1981) and in *Nothofagus cunninghamii* by Howard (1973b), although seed of *A. moschatum*, *Eucryphia lucida* and *N. cunninghamii* was successfully germinated by Hickey *et al.* (1983) in a 30°/20°C regime. The importance of high temperatures in limiting establishment from seed in the field is uncertain. Prolonged high temperatures in the range 30–35°C are unusual in the current distribution of forests containing these species, both in Victoria and Tasmania, but this feature may be relevant to the absence of these species from warmer sites.

A suitable combination of moisture and temperature is probably the most important factor determining seed germination under natural conditions (Mayer & Poljakoff-Mayber 1982). Howard (1973b) noted that suitable conditions for germination of *Nothofagus cunninghamii* occur within 8–9 months of seedfall and therefore reduction of viability with seed age is unlikely to be a limiting factor for regeneration. The same is true for *Eucryphia lucida*, *Atherosperma moschatum*, *N. gunnii*, *Athrotaxis selaginoides* and *A. cupressoides*. At low altitudes *N. cunninghamii*, *A. moschatum* and *E. lucida* germinate in autumn, within 1–2 months of seed release (fig. 3) and it is unlikely that the lack of germination recorded in dry-stored *A. moschatum* seed (also noted by Hickey *et al.* 1983)) would be a significant occurrence in the natural lowland environment. The greatly reduced germination score in apparently viable seed of *A. moschatum* at 900 m a.s.l. at Mt Field in 1985 is consistent with the secondary dormancy induced experimentally by cold moist or cold dry storage. However, in the field, cessation of dormancy was not observed to any significant degree, and it is not certain that light is the only

factor initiating release from this secondary dormancy. The environmental feature which is initiating the secondary dormancy observed at high altitudes is uncertain, since it is induced experimentally at both moderate and low temperatures and in both dry and moist conditions (except in the combination of moist, moderate temperatures). Any delay in germination will also result in greater mortality due to fungal attack (e.g. table 3) and insect attack. These characteristics may limit the ability of *A. moschatum* to colonise sites/microsites in which conditions suited to germination are consistently absent soon after seed release, e.g. at high altitudes.

The only species which may have soil-stored seed is *Phyllocladus aspleniifolius*; however, there are no data to indicate storage times of this species. *P. aspleniifolius* commonly appears on rainforest sites after fire (Kirkpatrick 1977, Hill & Read 1984); this may be the result either of soil storage and release from dormancy, whether "natural" or precipitated by the disturbance, or of efficient spatial dispersal. Kirkpatrick (1977) suggested that the early appearance of *P. aspleniifolius* on disturbed sites is due to bird dispersal. Seed of *P. aspleniifolius* has been recorded in pellets that have passed through the gut of birds, but the frequency of dispersal by animals and its effect on seed germination is uncertain for this species. The pattern of seed dormancy of *P. aspleniifolius* is similar to that of *Tasmannia lanceolata*, a species that commonly invades forest disturbances and has seeds that are commonly bird-dispersed (Read & Hill 1983). Howard (1974) noted that most *T. lanceolata* seedlings appeared 12 months after soil containing the seeds was collected from the field (18 months after the latest seedfall). She suggested that this was due to leaching of a germination inhibitor from the seed. It is likely that some dormancy mechanism is necessary to survive bird-dispersal.

Studies of the dynamics of populations of *Phyllocladus aspleniifolius* suggest that large-scale disturbance is an important feature of its regeneration (Read & Hill 1988a). Dormancy mechanisms, permitting a large soil store of seed which can survive a large-scale disturbance such as fire or severe frost, would facilitate rapid establishment, especially if the disturbance factor also precipitated release of the seed from dormancy. The infrequency of regeneration within rainforest may be related to the seed dormancy if, for example, a large canopy opening is required for dormancy release. However, Read & Hill (1988a) recorded relatively high *P. aspleniifolius* seedling densities on sites where it was failing to regenerate. Therefore it is unlikely that dormancy characteristics are directly limiting its regeneration within undisturbed rainforest, even though the percentage of its annual seed crop which germinates may possibly be small relative to that which remains dormant.

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REFERENCES

Amen, R.D., 1966: The extent and role of seed dormancy in alpine plants. *Quart. Rev. Biol.* 41: 271–281.

Ash, J., 1982: The *Nothofagus* Blume (Fagaceae) of New Guinea. *In* Gressitt, J.L. (Ed.): *BIOGEOGRAPHY AND ECOLOGY OF NEW GUINEA*. Dr W. Junk Publishers, The Hague: 355–380.

Bazzaz, F.A., 1979: The physiological ecology of plant succession. *Ann. Rev. Ecol. Syst.* 10: 351–371.

Bussell, W.T., 1968: The growth of some New Zealand trees. I. Growth in natural conditions. *N.Z. J. Bot.* 6: 63–75.

Cullen, P.J., 1987a: The Ecology and Biogeography of *Athrotaxis* D. Don. Unpubl. M.A. thesis, Univ. Tasm.

Cullen, P.J., 1987b: Regeneration patterns in populations of *Athrotaxis selaginoides* D. Don from Tasmania. *J. Biog.* 14: 39–51.

Grubb, P.J., 1977: The maintenance of species richness in plant communities: the importance of the regeneration niche. *Biol. Rev.* 52: 107–145.

Hickey, J.E., Blakesley, A.J. & Turner, B., 1983: Seedfall and germination of *Nothofagus cunninghamii* (Hook.) Oerst., *Eucryphia lucida* (Labill.) Baill. and *Atherosperma moschatum* Labill. Implications for regeneration practice. *Aust. For. Res.* 13: 21–28.

Hill, R.S. & Read, J., 1984: Post-fire regeneration of rainforest and mixed forest in western Tasmania. *Aust. J. Bot.* 32: 81–93.

Howard, T.M., 1973a: Studies in the ecology of *Nothofagus cunninghamii* Oerst. I. Natural regeneration on the Mt Donna Buang Massif, Victoria. *Aust. J. Bot.* 21: 67–78.

Howard, T.M., 1973b: Studies in the ecology of *Nothofagus cunninghamii* Oerst. II. Phenology. *Aust. J. Bot.* 21: 79–92.

HOWARD, T.M., 1973c: Studies in the ecology of *Nothofagus cunninghamii* Oerst. III. Two limiting factors: light intensity and water stress. *Aust. J. Bot.* 21: 93–102.

HOWARD, T.M., 1974: *Nothofagus cunninghamii* ecotonal stages. Buried viable seed in north-west Tasmania. *Proc. R. Soc. Vict.* 86: 137–142.

KIRKPATRICK, J.B., 1977: Native vegetation of the west coast region of Tasmania. *In* Banks, M.R. & Kirkpatrick, J.B. (Eds): *LANDSCAPE AND MAN*. Royal Society of Tasmania, Hobart: 55–80.

MAYER, A.M. & POLJAKOFF-MAYBER, A., 1982: *THE GERMINATION OF SEEDS*. 3rd edition, Pergamon Press, Oxford.

OGDEN, J., 1978: Investigations of the dendrochronology of the genus *Athrotaxis* D. Don (Taxodiaceae) in Tasmania. *Tree-Ring Bull.* 38: 1–13.

READ, J., 1981: Patterns and processes in the regeneration of cool temperate rainforest in old-fields. Unpubl. Hons. thesis, Univ. Tasm.

READ, J. & HILL, R.S., 1983: Rainforest invasion onto Tasmanian old-fields. *Aust. J. Ecol.* 8: 149–161.

READ, J. & HILL, R.S., 1985: Dynamics of *Nothofagus*-dominated rainforest on mainland Australia and lowland Tasmania. *Vegetatio* 63: 67–78.

READ, J. & HILL, R.S., 1988a: The dynamics of some rainforest associations in Tasmania. *J. Ecol.* 76: 558–584.

READ, J. & HILL, R.S., 1988b: Comparative responses to temperature of the major canopy species of Tasmanian cool temperate rainforest and their ecological significance. I. Foliar frost resistance. *Aust. J. Bot.* 36: 131–143.

SAYERS, R.L. & WARD, R.T., 1966: Germination responses in alpine species. *Bot. Gaz.* 127: 11–16.

WARDLE, J.A., 1984: *THE NEW ZEALAND BEECHES: ECOLOGY, UTILISATION AND MANAGEMENT*. New Zealand Forest Service, Wellington.

WAREING, P.F., 1956: Photoperiodism in woody plants. *A. Rev. Pl. Physiol.* 7: 191–214.

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STUDIES OF THE OAK LEAFMINER *PHYLLONORYCTER MESSANIELLA* (ZELLER) (LEPIDOPTERA: GRACILLARIIDAE) IN SOUTHERN TASMANIA

by R. Bashford and H. J. Elliott

(with three tables and two text-figures)

BASHFORD, R. & ELLIOTT, H.J., 1989 (31:x): Studies of the oak leafminer *Phyllonorycter messaniella* (Zeller) (Lepidoptera: Gracillariidae) in southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 223–228. ISSN 0080–4703. Forestry Commission, Hobart, Tasmania, Australia 7000.

The establishment of the oak leafminer on many *Quercus* species in southern Tasmania is recorded and indications of parasitisation levels given.
Key Words: *Phyllonorycter*, Lepidoptera, *Quercus*, Tasmania.

INTRODUCTION

The oak leafminer *Phyllonorycter messaniella* (Zeller) was first recorded in Australia by Common (1976) from Canberra and several sites within a 130 km radius of Sydney. Further establishment has been noted on Norfolk Island by Smithers (1977) and in Melbourne by New (1978, 1981). In Tasmania, Hardy *et al.* (1978) first recorded *P. messaniella* mines on several species of *Quercus* in Hobart and New Town. Since 1978 the distribution of *P. messaniella* within Tasmania has expanded considerably and it has become a serious pest of valued park and street oaks.

This paper reports studies of the leafminer's life history, mine establishment on host trees, parasitoids and a predator in southern Tasmania.

STUDY AREA AND METHODS

Twenty-two *Quercus* spp., both mature trees and seedlings, growing in the Oak Section of the Royal Tasmanian Botanical Gardens were sampled monthly for one year. Every month a total of 20 leaves were taken from each mature tree by sampling five shoots around the lower crown. The presence or absence of mines was noted on seedlings. The mines on each sample leaf were classified into one of the following four categories, established by New (1981), and egg counts were made:

(1) initial entry mines containing first instar larvae;
(2) blotch mines containing second and third instar larvae;
(3) tentiform mines containing fourth instar larvae and pupae;
(4) open mines following emergence or predation.

The mines were dissected while fresh, before desiccation could occur. Larval survival was assessed, based on the numbers of live and dead larvae found in the mines. Extra leaves were retained at 20°C for adult leafminer and parasite emergence. All parasitoid and moth pupae dissected from sample mines were retained for emergence at illumination periods of 11 day–13 night hours.

Three non-oak plant species growing in the Gardens, *Feijoa sellowiana*, *Castanea sativa* and *Fagus sylvatica* have been recorded by Wise (1953a) as hosts of *Phyllonorycter messaniella* in New Zealand. These species all carried mines during the sampling period (table 1).

RESULTS

Host Plants

Mine establishment on *Quercus* spp. and on other tree species attacked by *Phyllonorycter messaniella* during the sampling period are shown in table 1.

All species of *Quercus* except for *Q. palustris* were attacked at the study site.

Life History

The annual distribution of the four mine types established by New (1981) are shown for *Q. robur*,

TABLE 1

Phyllonorycter messaniella Mine Establishment on Host Trees

Tree species	Leaf area* (cm^2)	Number of mines/leaf†	Mines/cm^2	Max. mines per leaf
Quercus aliena	80.6	24.5	0.3	45
Q. ilex	14.3	18.1	1.3	43
Q. mirbeckii	72.2	20.7	0.3	41
Q. petraea	46.2	20.0	0.4	35
Q. virginiana	9.2	17.5	1.9	32
Q. robur	36.1	16.6	0.5	28
Q. suber	5.9	12.4	2.1	27
Q. garryana	43.7	16.9	0.4	27
Q. casteneifolia	41.2	11.9	0.3	26
Q. lanuginosa	26.0	13.0	0.5	24
Q. cerris	31.1	11.5	0.4	23
Q. incana	35.3	9.6	0.3	19
Q. macrocarpa	60.5	9.4	0.2	18
Q. coccinea	89.0	8.9	0.1	15
Q. hartwissiana (seedling)	37.8	3.4	0.1	10
Q. serrata (seedling)	19.3	0.9	0.1	4
Q. canariensis (seedling)	14.3	ns	ns	4
Q. bicolor (seedling)	50.4	ns	ns	3
Q. rubra	38.6	ns	ns	3
Q. rubra (seedling)‡	73.9	ns	ns	3
Q. acutissima (seedling)	22.7	ns	ns	3
Castanea sativa	58.8	4.2	0.1	3
Fagus sylvatica	14.3	1.4	0.1	3
Feijoa sellowiana	14.3	1.1	0.1	2
Q. borealis (seedling)	89.9	ns	ns	1
Q. canadiensis	12.6	ns	ns	1
Q. palustris (seedling)	18.5	0	0	0

* mean of 10 mature leaves.
† monthly mean.
‡ small sample.
ns not sampled.

a common deciduous host, and for *Q. suber*, the only evergreen host in the study area (fig. 1). Most deciduous hosts had a similar pattern of *Phyllonorycter messaniella* mine establishment and development, with peak establishment (i.e. incidence of Mine Type 1) occurring in October. The common deciduous host *Q. robur* supported two generations of *P. messaniella* per year but some larger-leaved species such as *Q. mirbeckii* and *Q. petra* retained their leaves for nine to ten months of the year and supported three generations of *P. messaniella* per year.

In the winter months, the evergreen *Q. suber* was colonised by *P. messaniella* when deciduous oaks were leafless. In summer, *Q. suber* leaves are attractive oviposition sites for *P. messaniella* but larval survival is low, probably due to desiccation. The contrasting pattern of oviposition by *P. messaniella* on *Q. suber* and *Q. robur* and mine density and larval survival are shown in table 2.

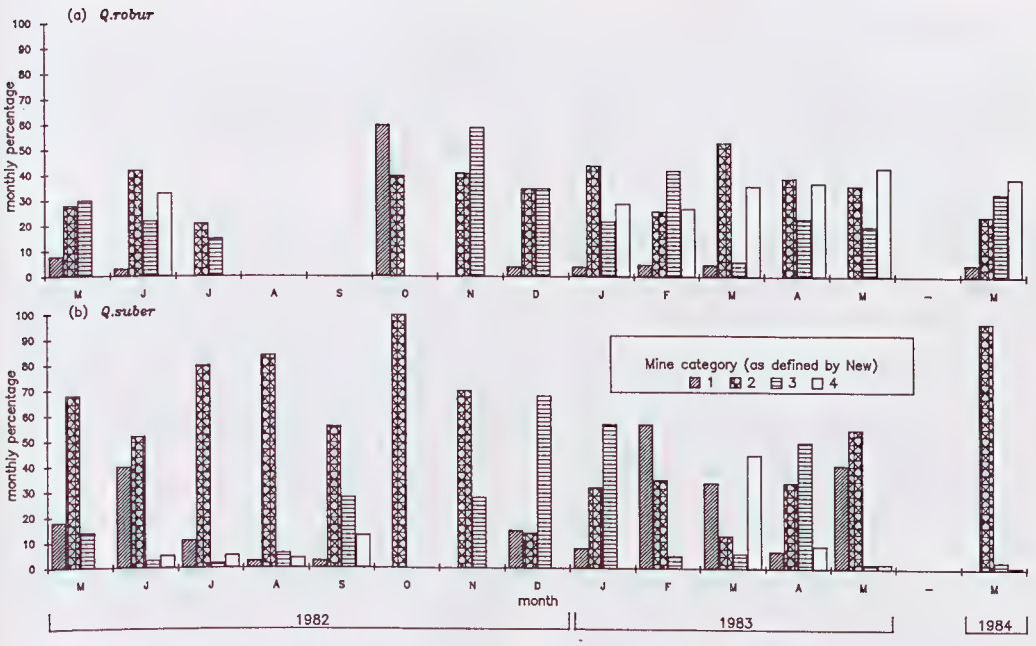

FIG. 1 — Comparison of mine development on (A) Quercus robur *and (B)* Q. suber.

TABLE 2

Oviposition and Larval Survival on the Hosts *Quercus suber* and *Q. robur.*

Period sampled		*Q. suber* (evergreen)			*Q. robur* (deciduous)		
		Eggs/ leaf	Mines/ leaf	Survival %	Eggs/ leaf	Mines/ leaf	Survival %
1982	May	3.9	2.0	20	0	16.6	5
	Jun	3.6	9.0	63	0	10.7	1
	Jul	1.4	9.5	16	0	3.6	0
	Aug	0	12.4	33	–	–	–
	Sep	0	4.7	28	–	–	–
	Oct	0	0.6	0	0.5	0.3	5
	Nov	0.1	0.4	29	0.2	1.7	53
	Dec	0.3	0.7	14	0.2	1.3	38
1983	Jan	0.7	1.1	14	0	2.8	25
	Feb	0.5	0.9	6	0.1	2.6	29
	Mar	0.8	0.8	0	0.4	7.3	19
	Apr	4.8	0.6	17	0	4.5	17
	May	7.2	9.0	91	0	5.0	1
1984	May	19.8	5.7	25	0	6.5	9
1985	May	7.7	2.8	29	0	3.9	27

Parasitisation and Predation

Ten species of chalcidoid wasps (Hymenoptera), including one hyperparasite, were reared from *Phyllonorycter messaniella* mines. One predator was found associated with the mines. Adults of this species were reared from pupae collected in damaged mines (table 3).

The spring and summer generations of *P. messaniella* on all host species are heavily parasitised, while the overwintering generation, on evergreen oaks, has low levels of parasitisation (fig. 2).

Peak levels of parasitisation occurred early in the spring, with up to 57% of mines on *Q. suber* containing parasitoid larvae or pupae. No endoparasitic larvae were found when *P. messaniella* larvae were dissected. Parasitisation in mines on *Q. robur* peaked at 22%. There was considerable variation in levels of parasitisation on different tree species.

Elachertus sp. B (Hymenoptera:Eulophidae) comprised 56% of the total parasitoid emergence while its hyperparasite *Cirrospilus margiscutellum* (Girault) (Hymenoptera:Eulophidae) totalled 29%.

Adults of the hemerobiid *Micromus tasmaniae* (Walker) (Neuroptera) were observed feeding on freshly-deposited eggs. Larval predation was not observed but hemerobiid larvae were found in damaged mines containing the remains of *P. messaniella* larvae. The majority of adults of *M. tasmaniae* were collected on *Q. suber* samples and the majority of pupae of *M. tasmaniae* were found in damaged mines on this tree species.

TABLE 3

Natural Enemies of *Phyllonorycter messaniella* in Southern Tasmania

Parasitoids	**Hymenoptera**
Gen nr. *Elachertus* sp. A	Eulophidae
Gen. nr. *Elachertus* sp. B	Eulophidae
Gen. indet. sp. A	Eulophidae
Gen. indet. sp. B	Eulophidae
Tetrastichus sp.	Eulophidae
Gen. indet. sp. A	Pteromalidae
Gen. indet. sp. B	Pteromalidae
Sierola sp.	Bethylidae
Goniozus sp.	Bethylidae
Hyperparasite	
Cirrospilus margiscutellum (Grlt.)*	Eulophidae
Predator	**Neuroptera**
Micromus tasmaniae Walker	Hemerobiidae

* This hyperparasite attacked only Gen. nr. *Elachertus* spp. A & B.

DISCUSSION

The highest densities of leaf mines recorded in this survey were 45 mines per leaf on *Quercus aliena* and 41 mines per leaf on *Q. mirbeckii*. *Quercus robur* carried a maximum of 28 mines per leaf. Wise (1953b) records up to 40 mines per leaf on *Q. robur* in New Zealand while Smithers (1977) found 65 mines on leaves of an unidentified oak on Norfolk Island.

Maier (1983) showed that apple leaves abscissed significantly earlier if mined by *Phyllonorycter crataegella*. Pritchard & James (1984) also demonstrated accelerated leaf loss due to *P. messaniella* on holm oak having moderate levels of infestation (12–31%). From observation of oak species at the Hobart study site, high mine density appears to cause early senescence of leaves at the end of summer, with the result that development of many mines was incomplete.

During the collection of leaf samples, no difference in frequency of mined leaves was apparent to a height of 2.6 m. However, visual appraisal using binoculars suggested decreasing numbers of mined leaves in the upper half of sampled trees. Miller (1973) showed a significant decrease in mine density with height of a mature tree but no relationship between mine density and aspect.

At the Hobart study site, adults of *P. messaniella* are in flight for most months of the year, as three generations are supported by the range of deciduous and evergreen oak species available. The evergreen species *Q. suber* enables a successful winter generation to develop, with adults emerging in synchrony with the spring flush of leaf growth on deciduous oaks. In Europe, the holm oak *Q. ilex*, which is considered to be the primary host species, supports two winter generations (Delucchi 1958). The summer generation prefers the soft tissues of *Castanea sativa*. This alternation of hosts is reflected in Tasmania, where the evergreen *Q. suber* supports the small winter generation and the two summer generations are carried on both deciduous and evergreen oak species.

Parasitoids of *P. messaniella* in Tasmania are native insects that have previously been found to

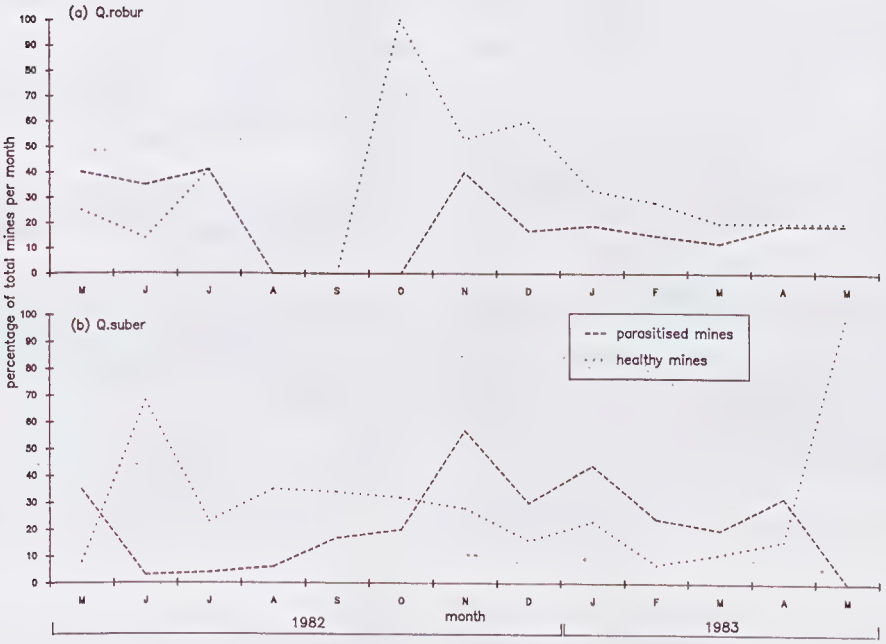

FIG. 2 — Frequency of healthy and parasitised mines of Phyllonorycter messaniella *on* Quercus robur *and* Q. suber *(—— parasitised mines, ... healthy mines).*

be associated with native gall-forming and mining insects (Forestry Commission, unpubl. studies). A similar situation occurs in Canberra and NSW, where six native parasitoid species are recorded from *P. messaniella* mines by Common (1976). In Melbourne, eight native species are noted by New (1981). This contrasts with parasitisation in New Zealand, peaking at 81.8%, caused only by introduced species (Swan 1973, Given 1959). Several species of the hymenopteran genera *Elachertus* Spinola, *Cirrospilus* Westwood and *Tetrastichus* Haliday were recovered by Delucchi (1958) as part of the parasitoid complex of *P. messaniella* in Europe.

The oak leafminer is now widely distributed throughout Tasmania. The trees become unsightly due to the blotchy appearance of the mines and early leaf senescence and reduced growth rates may result. The parasitoid complex does not significantly control populations of *Phyllonorycter messaniella*, nor limit the formation of mines which cause cosmetic and horticultural problems. The leaves of some *Quercus* species, such as *Q. palustris*, are apparently less attractive as oviposition sites. The planting of such species in parks and gardens may reduce the visual impact caused by mine formation.

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REFERENCES

COMMON, I.F.B., 1976: The oak leafminer *Phyllonorycter messaniella* (Lepidoptera: Gracillariidae) established in Australia. *J. Aust. Ent. Soc.* 15(4): 471–473.

DELUCCHI, V.L., 1958: *Lithocolletis messaniella* Zeller: Analysis of some mortality factors with particular reference to its parasite complex. *Entomophaga* 3(3): 203–270.

GIVEN, B.B., 1959: Biological control factors influencing populations of oak leafminer, *Lithocolletis messaniella* Zeller, in New Zealand including the introduction of parasites. *N.Z. J. Agric. Res.* 2: 124–133.

HARDY, R.J., TERAUDS, A., RAPLEY, P.E.L., WILLIAMS, M.A., IRESON, J.E. & MILLER, L.A., *ET AL.*, 1978: Insect pest occurrences in Tasmania 1977–78. *Insect Pest Survey No.10*. Tasmanian Department of Agriculture: 19.

MAIER, C.T., 1983: Effect of the apple blotch leafminer (Lepidoptera: Gracillariidae) on apple leaf abscission. *J. Econ. Entomol.* 76: 1265–1268.

MILLER, P.F., 1973: The biology of some *Phyllonorycter* species mining leaves of oak and beech. *J. Nat. Hist.* 7: 391–409.

NEW, T.R., 1978: Notes on the oak leafminer in the Melbourne area. *Vic. Nat.* 95: 195–197.

NEW, T.R., 1981: The oak leafminer, *Phyllonorycter messaniella* (Zeller) (Lepidoptera: Gracillariidae) in Melbourne. *Aust. J. Zool.* 29: 895–905.

PRITCHARD, I.M. & JAMES, R., 1984: Leaf mines; their effect on leaf longevity. *Oecologia* 64: 132–139.

SMITHERS, C.N., 1977: The oak leafminer, *Phyllonorycter messaniella* (Zeller) (Lepidoptera:Gracillariidae) established on Norfolk Island. *Aust. Ent. Mag.* 4(1): 16.

SWAN, D.I., 1973: Evaluation of biological control of the oak leafminer *Phyllonorycter messaniella* (Zeller) (Lepidoptera, Gracillariidae) in New Zealand. *Bull. Ent. Res.* 63(1): 49–55.

WISE, K.A.J., 1953a: Host plants of Lithocolletis messaniella. *N.Z. J. Sci. Tech.* 35(A): 172–174.

WISE, K.A.J., 1953b: Occurrence of the oak blotch miner *Lithocolletis messaniella* Zeller (Lepidoptera: Gracillariidae) in New Zealand. *Trans. R. Soc. N.Z.* 81(1): 65–66.

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THE CONSERVATION OF ORIGINAL VEGETATION REMNANTS IN THE MIDLANDS, TASMANIA

by R. J. Fensham and J. B. Kirkpatrick

(with two tables, three text-figures and an appendix)

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Following 180 years of agricultural settlement, the Midlands area of Tasmania has been drastically transformed and 83% of the original area of native vegetation has been replaced. By comparing information from two recent intensive floristic surveys with historical botanical records, it was determined that 11.8% of the higher plant flora has vanished. With current rates of change and land tenure, it is probable that further extinctions will occur in this environment. Grazing was found to increase significantly native species richness on loams and clays, although the same relationship was not evident on sandy soils. The management of grassy remnants should include regular burning and/or grazing as a means of intermittently depleting the grass sward. Many herbaceous exotics are habitat specific, and it is suggested that their passive spread is not an immediate threat to native vegetation on well-drained land. The long-term viability of native vegetation may, however, necessitate the implementation of simple management programs designed to maintain native species diversity and to minimise the spread of the more vigorous woody exotics.
Key Words: grassy vegetation, species richness, grazing, burning, exotics, Tasmanian Midlands, conservation, extinction.

THE CURRENT STATUS OF MIDLANDS VEGETATION

The Midlands area of Tasmania (fig. 1) was one of the first areas developed for agriculture in Australia and, since the early part of last century, the area has been radically transformed (Kirkpatrick *et al.* 1988: 17–21). Today, a vast expanse of cultivated ground extends to the base of the surrounding escarpments. Plant communities and species that were restricted to these agriculturally desirable habitats are now confined to scattered refugia that have accidentally avoided destruction. In the period from European settlement to 1985, native vegetation was reduced to 16.9% of its original area (fig. 2). With current rates of change, virtually all of the remaining vegetation of the Midlands could be destroyed by forestry and agricultural exploitation; 99.3% of land is privately owned.

The Midlands form a natural landscape unit, defined by its mountainous borders, low altitudes, dry climate, broad fertile river valleys and plains. As well as prime agricultural land, it contains dissected dolerite hills and ancient lateritised surfaces. Fensham (1989) identified 14 terrestrial plant communities that are derived from five gross formations, identifiable by their structure or overstorey dominants. These formations are *Eucalyptus amygdalina* forest, *E. viminalis* woodland, *E. pauciflora* woodland, *E. ovata* woodland and *Poa labillardieri* tussock grassland.

Specht (1981) identified the savannah woodlands of temperate southeastern Australia as one of seven major plant formations virtually absent from Australia's reserve network. Surveys of Tasmania's dry forests and grassy ecosystems (Duncan & Brown 1985, Kirkpatrick *et al.* 1988) have found all of the major dryland Midlands communities, with the exception of *E. viminalis* woodlands, to be poorly reserved or unreserved.

Most of the Midlands consisted of sparsely wooded plains dominated by *E. pauciflora* and/or *E. ovata*. These formation survive only in very small areas and are extremely vulnerable to further landscape change. Many roadside remnants continue to be damaged or destroyed by road widening, rerouting and herbicide spraying. In 1985, the Campbell Town cemetery was in excellent native condition and represented one of the last woodland remnants on basalt soils. However, recent "clean up" attempts have excised half of its area into the adjoining paddock, poisoned much of the remainder and disturbed the ground, destroying one of the three known populations of one of Australia's rarest plant species *Colobanthus* aff. *strictus*.

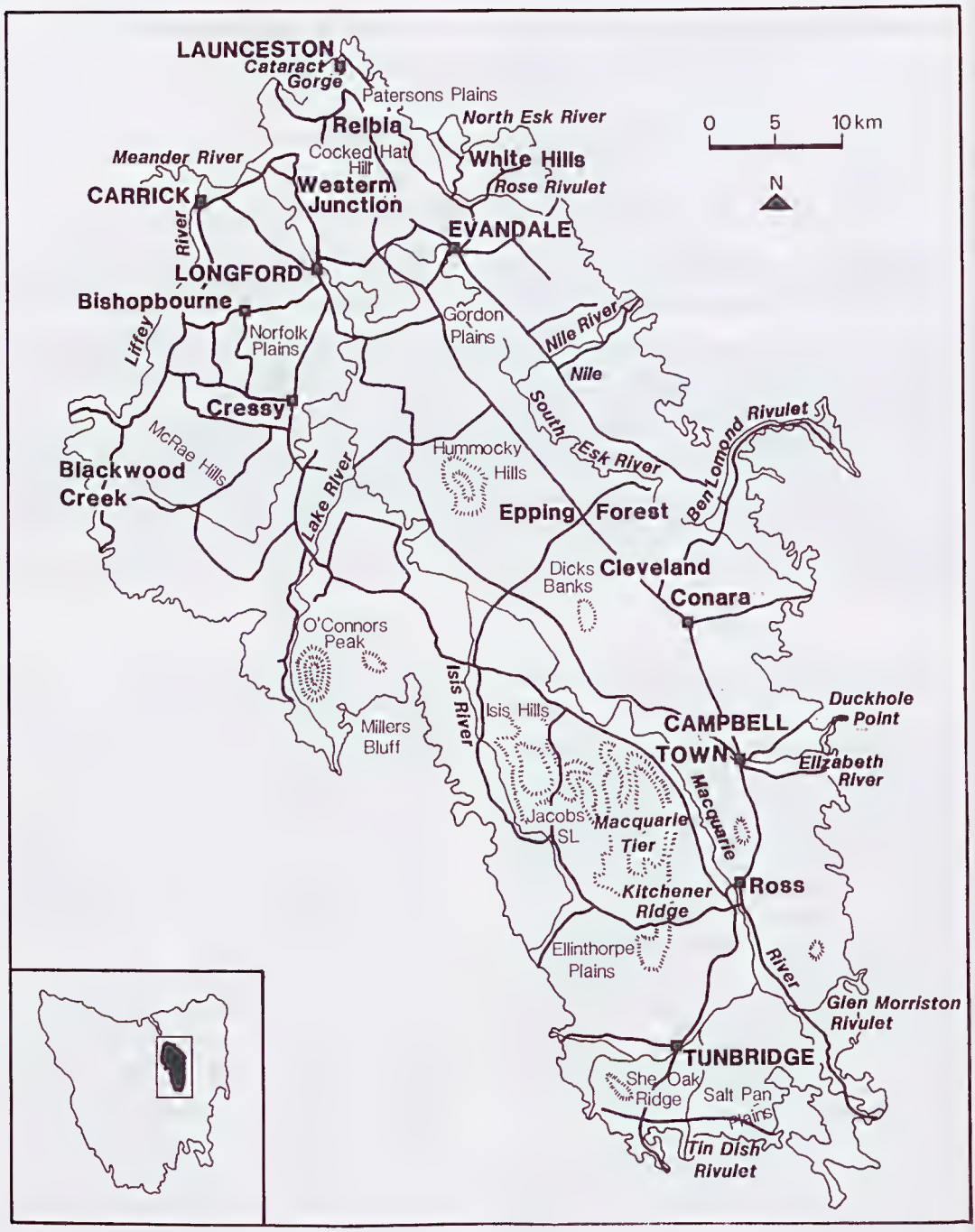

FIG. 1 — Locality map.

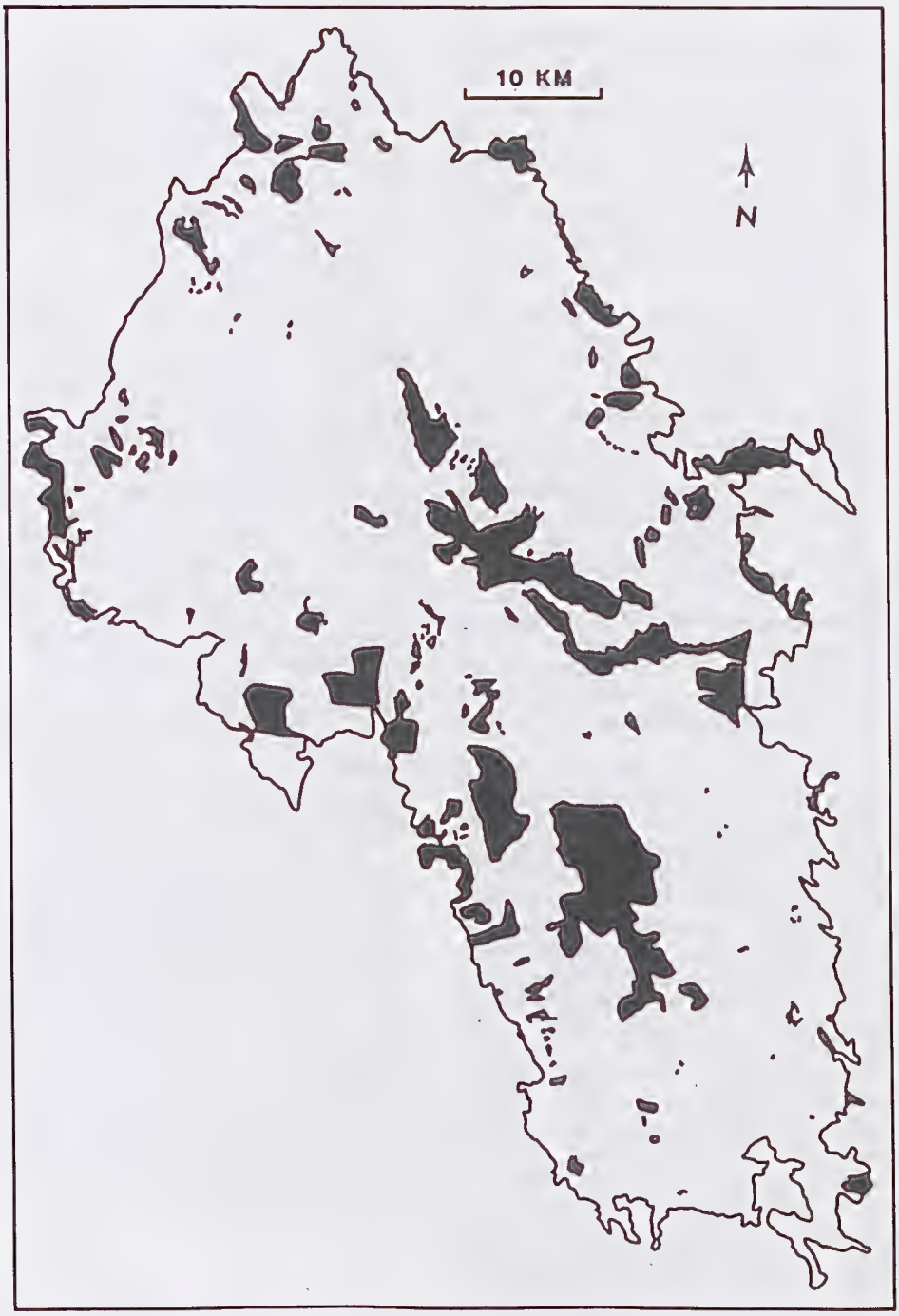

FIG. 2 — Native vegetation remnants, including regenerated clearfell coupes and native pasture with depleted overstoreys; c. 1988.

Eucalyptus amygdalina forest covered large areas of the Midlands on poorer soils. However, in recent decades it has been rapidly cleared (fig. 2). The grasslands of the river flats have all been cultivated, with the exception of a small area on the Macquarie River surrounded by steep rocky banks, and a few fragments heavily invaded by exotics. The number of extinct Midlands plant species that were known only from such habitats (appendix) suggests that the full range of these communities has not survived.

The riparian shrub communities are still relatively intact on the edges of the study area at the Macquarie and Elizabeth Rivers and Cataract Gorge. Apart from these peripheral areas riparian communities have virtually disappeared, with the exception of a few small fragments in moderately grazed or rocky situations. The riparian habitat seems particularly susceptible to invasion by woody weeds, especially gorse (*Ulex europaeus*) and willows (*Salix alba*), and the native communities have probably been eliminated by grazing.

The aquatic communities still have apparently original complements of native plants as well as many exotic taxa. There is no evidence of the eutrophication that has so seriously affected waterways of intensively cultivated areas in other parts of the world.

Thirty-four per cent of the area under wetlands has been drained, while a further 23% has been affected by artificial changes of water level (fig. 3). Most of the wetlands have suffered from drainage attempts, although Smiths Lagoon (wetland no.30) has been impounded and Bar Lagoon (wetland no.42) has deepened as a result of increased runoff following clearance and gravel scraping in nearby Verwood Forest (G. Dowling, pers. comm. 1986). Of the remaining wetlands, the infrequently inundated margins are susceptible to exotic invasion following disturbance by introduced grazing animals. Many of these communities have depleted native species complements and are dominated by the exotic herb *Plantago coronopus*.

A search of botanical records and herbarium collections (see appendix for these references) revealed the native species that have been recorded from the Midlands; those not found at these localities in the course of the surveys of Fensham (1989) and Kirkpatrick & Harwood (1983a,b) are indicated. Where possible, the localities of old records were checked for evidence of the existence of a plant species. However, most old records refer to localities where the chances of finding native species is slight, such as R.C. Gunn's collections from *Penquite* — now a part of suburban Launceston (Gunn 1842). Some ephemeral species, particularly orchids, may still be present in the Midlands. Herbarium collections marked with the general locality "Launceston" were not included, as they may have occurred outside the study area. Based on this estimate, 59 of the 499 higher native plant species recorded from the Midlands are extinct. Full details of these historical records can be found in Fensham (1985).

Apart from the Orchidaceae, most of the extinct species were associated with riverine habitats — an indication of the degree of native vegetation displacement in these environments. *Deyeuxia lawrencii*, *Goodenia amplexans*, *Isoetes drummondii*, *Myriophyllum glomeratum*, *Prostanthera cuneata* and *Senecio macrocarpus* may now be extinct in Tasmania, although the record for the *Goodenia amplexans* may refer to a collection in the Melbourne Herbarium marked "Nile Rivulet", which could be a mainland locality. Temporary displacement of aquatic species has been documented for both lentic (Holmes & Whitton 1977) and lotic water (Millar 1973) and, given that not all waters were thoroughly surveyed, it is probable that the aquatic species *Trithuria submersa* and *Utricularia australis* still occur in the Midlands. *Chenopodium pumilio* and *Euphrasia scabra* have been germinated recently from soil collected near Ross (L. Gilfedder, pers. comm. 1988), although these annuals have not been observed in the field.

It is unlikely that the full range of plant communities in the Midlands has survived. Dimmock & Loveday (1953) described a hummocky complex north of Campbell Town as a "complex of low mounds and self-mulching depressions". This is physically comparable to the gilgai complex described by Leeper (1952). The mainland gilgai complexes have been documented as having particular plant associations corresponding to their micro relief features (Williams 1955). The former extent of these formations is unknown. The "hummocky" complexes in the Campbell Town area have nearly all been cultivated and none were located in the study area with native plant cover.

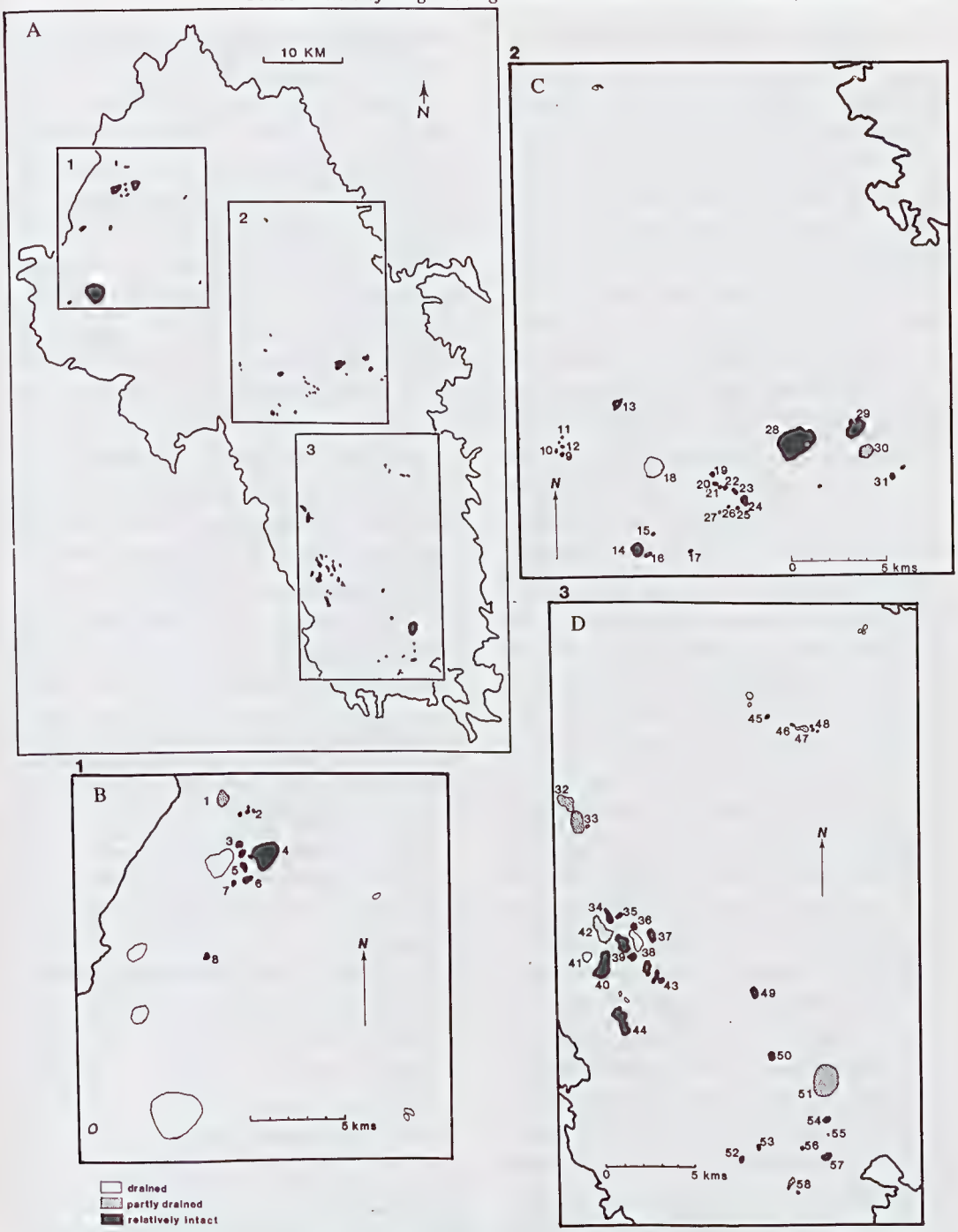

FIG. 3 — (A) Distribution of wetlands in the Midlands showing areas covered by (B), (C) and (D); (B) status of wetlands in area 1; (C) status of wetlands in area 2; (D) status of wetlands in area 3.

STRATEGIES FOR CONSERVATION

While conservation of major structural formations is desirable, detailed botanical surveys allow for the determination of areas that most efficiently conserve the maximum number of species. This survey discovered several species not previously known from Tasmania, which indicates the importance of survey work in endangered habitats. The appendix shows the Midlands species that are unreserved in Tasmania. The species reservation status was established from herbarium and literature searches and discussion with M. Brown, F. Duncan and L. Gilfedder.

Reservation of areas of Epping Forest would preserve *Eucalyptus amygdalina* forest and could include the unreserved species *Amphibromus macrorhinus*, *A. neesii*, *Aphelia gracilis*, *A. pumilio*, *Brunonia australis*, *Caesia parvifolia* var. *vittata*, *Caladenia clavigera*, *Calochilus imberbis*, *Centipeda minima*, *Cyperus tenellus*, *Eragrostis benthamii*, *Glycine latrobeana*, *Haloragis aspera*, *Helipterum australe*, *H. demissum*, *Hypoxis vaginata*, *Lomandra nana*, *Ophioglossum lusitanicum*, *Pilularia novae-hollandiae*, *Poa hookeri*, *P. pratermissa*, *Ptilotus spathulatus*, *Pultenaea humilis*, *P. prostrata* and *Schoenus latelaminatus*. Reservation of an appropriate area of grassy native vegetation in the Tunbridge area would preserve *Eucalyptus pauciflora* woodland and could include the unreserved species *Asperula scoparia*, *Brachyscome rigidula*, *Calocephalus lacteus*, *Craspedia* sp. "Tunbridge", *Cryptandra amara*, *Danthonia carphoides* var. *angustior*, *Dianella longifolia*, *Isoetopsis graminifolia*, *Lomandra nana*, *Poa hookeri*, *Prasophyllum odoratum*, *Pterostylis biseta*, *Scleranthus diander*, *Stipa scabra*, *Pultenaea prostrata*, *Velleia paradoxa*, *Vittadinia cuneata*, *V. gracilis*, *V. muelleri*, *Wilsonia rotundifolia* and the endemic species *Stackhousia gunnii*. The Tunbridge tip site is on Crown Land and most of it has recently been informally declared a refuge area. The area has been subject to some bulldozing and is probably less desirable for reservation than some of the private paddocks in the area. The case for a reserve in Epping Forest is strengthened by its unusually high concentrations of the restricted endemic marsupial *Bettongia gaimardi* (Taylor 1988).

The Elizabeth River gorge has already been identified as an area of high priority for plant conservation because of its large healthy populations of the rare endemic species *Acacia axillaris* (Brown *et al.* 1983). The area also includes another unreserved endemic *Epacris exserta* and the unreserved *Pimelea pauciflora*.

Cataract Gorge in Launceston provides another opportunity of protecting vulnerable species. The presence of the unreserved species *Anogramma leptophylla*, *Doodia media*, *Helichrysum* aff. *semipapposum*, *Micrantheum hexandrum* and the unreserved endemic species *Callitris oblonga* and *Epacris exserta* make this area of public land extremely suitable for reservation.

The wetlands in the study were not identified as high priority areas for plant species conservation by Kirkpatrick & Harwood (1983b) but since their work the endemic species *Ranunculus prasinus* has been described (Menadue & Crowden 1985). This species is only known from Near Lagoon (wetland no.49) and White Lagoon (wetland no.50). Near Lagoon has a population of *Bolboschoenus caldwellii* and both lagoons have populations of *Schoenoplectus validus* and extensive herbfields dominated by *Wilsonia rotundifolia*, all of which are unreserved in the State. A recent analysis of significant wetlands of Tasmania includes Near Lagoon (Kirkpatrick & Tyler 1988).

Other unreserved species of isolated occurrence on private land or small refuge areas in the Midlands may require protection. While control by the appropriate government body is the most desirable means of protecting valuable natural areas, private ownership is not necessarily incompatible with nature conservation. A private trust fund, for purchasing private land for nature conservation, has been established by the Tasmanian Conservation Trust. However, the owners of valuable Midlands regions have proven reluctant to relinquish even the smallest areas (D. Watts, pers. comm. 1987). The reluctance of governments to purchase, and private owners to part with land suggests alternative means of protection may be necessary. The introduction of legislation such as in South Australia, Victoria and New South Wales, where private landholders receive incentives to protect and preserve natural environments and are required to abide by a suitable management plan (Leigh *et al.* 1984), would be extremely appropriate for an area like the Midlands. Several landowners have indicated their interest, given some financial incentive, in protecting native vegetation on their land. One small area of land of a sympathetic landowner is inhabited by three rare plant species; it could be simply protected by a relatively short fence.

VIABILITY AND MANAGEMENT OF SMALL RESERVES IN GRASSY VEGETATION

Problems

The viability of small reserves has been the subject of international debate (e.g. Diamond 1975, Simberloff & Abele 1976, Higgs 1981, Brown & Hopkins 1983). Whatever the theoretical implications of this discussion, it is certain that the suitability of a particular area as a nature reserve will be idiosyncratic, depending on its significance, the availability of alternatives, the size and shape of the area, the behaviour of the particular vegetation type in the face of surrounding land-use, management problems and the aims of the conservation effort.

One of the most serious problems affecting native vegetation in small reserves in agricultural districts is the edge effect of management practices on adjacent land. The use of herbicides is particularly hazardous; other practices may have less dramatic effects, but nonetheless be deleterious. Drift from fertiliser application has the most serious effect on native vegetation on infertile substrates (Kirkpatrick 1977), particularly where aerial spreading techniques are employed. Thus, a viable reserve on relatively infertile substrates, such as those supporting *Eucalyptus amygdalina* forest in the Midlands, would need to be larger than one on fertile substrates. However, few remnants on any substrate were observed adjacent to improved pasture. Specht & Cleland (1961) suggest that buffer zones should be established to absorb the effects of adjacent land-use patterns.

Mechanical ground disturbance and herbicide spraying seriously affect all native vegetation in the Midlands, particularly grassy vegetation on fertile substrates. The prevention of such incursions should ensure the viability of even the smallest remnants, such as roadside and rail verges, for the immediate future, until more adequate reserves are established or plant species relocated to safer habitats.

Species Richness

The maintenance of species richness in grassy vegetation on fertile soils in southeastern Australia seems to require some mechanism for regularly reducing the biomass of the perennial grasses (Stuwe & Parsons 1977, Kirkpatrick 1986, Dickinson & Kirkpatrick 1986). This hypothesis was tested for the Midlands quadrat data set (Fensham 1989) on substrates with a range of fertilities. Quadrats were placed into three broad groups, using the soil textural classes of McDonald *et al.* (1984): those on dolerite with loams or heavier soils, those on depositional material with light sandy clay loams or lighter soils, and a third intermediate group containing quadrats that could not be defined by these criteria. The Cressy Research Farm and all private property with the exception of two areas not subjected to grazing for several years (as confirmed by the owners) constituted the grazing group. In addition to these two areas the ungrazed group comprised the road and rail reserves, cemeteries, ungrazed Crown Land and city parks. Native species richness was determined for each of the 180 10×1 m quadrats. The percentage frequencies of the individual species were compared between the grazed and ungrazed plots using Student's t-test.

The abundances of grasses, sedges, annual herbs, perennial herbs and shrubs were each compared between grazed and ungrazed sites. Only species with a percentage frequency of more than 10% in any one comparison were included in the following analysis. Each 20% difference between the grazed and the ungrazed groups was regarded as a unit. Thus, if a species had a frequency of 75% in the ungrazed group and 30% in the grazed group, the abundance of that species in the ungrazed groups was 250% greater than the grazed group and the species received a score of 12. Where a species was absent from a group it was given a percentage frequency equivalent to it occurring in one quadrat. The units for all species in each life-form were totalled for both the grazed and the ungrazed treatment. If the importance of grazing did not vary between life-forms, it would be expected that the proportions of units in each treatment for a particular life-form would be equal to the proportion of units in each treatment for the total number of species. The significance of the deviation from the expected value was tested using the chi-squared test.

The comparison between mean native species richness on grazed and ungrazed sites revealed different effects on different soil types and differing life-form groups. It appears that native species richness is increased by grazing on fertile dolerite soils ($t = 5.8$, $P < 0.001$) and other clays and loams ($t = 2.5$, $P < 0.02$), but not on infertile sandy soils.

While grazing does not dramatically affect species richness in the grassy heath understoreys on infertile ground, it can influence community composition. *Leucopogon virgatus* has been

virtually excluded from some areas of forest, leaving *Hibbertia riparia* as the single dominant shrub. When a fence separates an area of forest where grazing has been less intense, *Leucopogon virgatus* is a codominant member of the understorey.

The percentage frequencies of species of the understorey that were most affected by grazing on fertile soil (all sites except those on sandy soils) are shown in table 1. Small annual herbs and geophytes decline most significantly (chi-squared = 16, $P < 0.001$ and chi-squared = 3.3, $P < 0.1$ respectively) in the absence of grazing. The larger (*Helichrysum apiculatum*, *Dianella* spp.) or twining (*Asperula conferta*, *Convolvulus erubescens*) growth-forms may allow some herbaceous species to compete successfully in the ungrazed grass sward.

Grasses showed varying responses, with *Deyeuxia quadriseta* and most of the shorter grasses such as *Agrostis aemula*, *Danthonia laevis*, *D. tenuior*, *D. carphoides* var. *angustior* and

TABLE 1

Percentage Frequency of Species in Ungrazed and Grazed Treatment Groups* for Quadrats Located on Fertile Ground

	Ungrazed	Grazed
Grasses		
Dichelachne crinita	50	29.4
Elymus scabrus	88.6	64.7
Stipa mollis	18.2	8.8
S. semibarbata	36.4	17.7
S. stuposa	84.1	61.8
Agrostis aemula	18.2	38.2
Danthonia carphoides	36.2	56.2
D. laevis	40.9	70.6
D. tenuior	2.3	26.5
Ehrharta stipoides	43.2	94.1
Pentapogon quadrifidus	34.1	73.5
Sedges and rushes		
Centrolepis aristata	2.3	11.8
Schoenus apogon	61.4	88.2
Juncus capitatus	2.3	17.7
J. subsecundus	0	20.6
Annual herbs		
Senecio quadridentatus	31.8	8.8
Daucus glochidiatus	11.4	38.2
Poranthera microphylla	11.4	41.2
Wahlenbergia gracilis	13.6	38.2
W. gymnoclada	4.6	20.6
W. multicaulis	4.6	44.1
W. stricta	15.9	35.3
Perennial herbs		
Acaena ovina	59.1	26.5
Asperula conferta	43.2	20.6
Caesia vittata	18.2	2.9
Convolvulus erubescens	77.3	47.1
Dianella longifolia	20.5	2.9
D. revoluta	15.9	5.9
Helichrysum apiculatum	50	17.6
Vittadinia muelleri	18.2	0
Acaena echinata	36.4	82.4
Arthropodium milleflorum	6.8	14.7
Dichondra repens	18.2	82.4
Galium gaudichaudii	4.6	14.7
Glycine latrobeana	0	11.8
Gnaphalium collinum	25	61.8
Gonocarpus tetragynus	34.1	55.9
Hydrocotyle sibthorpioides	2.3	14.7
Hypericum gramineum	18.2	67.7
Hypoxis hygrometrica	2.3	11.8
Leptorhynchos squamatus	52.3	76.5
Lomandra longifolia	27.3	64.7
Ptilotus spathulatus	11.5	23
Solenogyne dominii	13.6	38.2
S. gunnii	15.9	35.3
Veronica calycina	6.8	14.7
V. gracilis	9.1	26.5
Viola hederacea	0	11.8
Wurmbea dioicia	6.8	14.7
Trees and shrubs		
Bossiaea riparia	15.9	0
Eucalyptus pauciflora	20.5	5.9
Exocarpos cupressiformis	15.9	5.9
Acacia mearnsii	6.8	20.6
Banksia marginata	4.6	11.8
Bursaria spinosa	40.9	73.5
Eucalyptus viminalis	27.3	73.5
Hibbertia hirsuta	25	61.8
Lissanthe strigosa	36.4	70.6
	n = 44	n = 34

* Only species occurring in greater than 10% of either treatment group, where the difference between treatments is more than double or greater than 20%, are included.

Ehrharta stipoides being favoured by grazing. *Themeda triandra* declined from 100% to 82.4%, suggesting a cause for the disappearance of this species on extremely heavily grazed native pastures. All relatively common shrub species of fertile environments were more common in grazed areas, with the exception of *Bossiaea riparia*, which occurs in paddocks but was not recorded in an ungrazed area.

The maintenance of species richness on the fertile remnants requires some mechanism for intermittently depleting the grass sward. Grazing by marsupial herbivores may be the most suitable method (Kirkpatrick 1986) though, given the animosity towards native animals in agricultural areas, the use of fire may be an appropriate tool for periodically opening the grass canopy. Stuwe & Parsons (1977) have suggested that exotic species richness is greater in native grassland that is regularly burnt than in the same vegetation type subject to different treatments. However, there is animosity to burning in agricultural areas and, if this practice is not possible, moderate grazing by sheep may be an alternative, though less desirable. Scarlett & Parsons (1982) have pointed out that the timing and interactions of grazing and firing may be critical to the survival of rare legumes in analogous vegetation in Victoria. Current research being conducted on Tasmanian grassland species may provide information on their survival requirements (L. Gilfedder and J. Whinam, pers. comm. 1979).

EXOTIC SPECIES

Exotic plant species in the Midlands were recorded from each quadrat during a recent survey of patterns of native vegetation (Fensham 1989); their percentage frequencies, in the classificatory groups established from the native vegetation (Fensham 1989), are shown in table 2. In some instances different levels of invasion reflect the site selection procedure. Less common environments were sampled with higher exotic complements than would have been tolerated for the more frequent environments. This is the case for the heavily exploited *Eucalyptus pauciflora* woodlands (groups 8, 9 and 10), where the frequencies of exotics are high. Exotic species abundance may also be a reflection of how recently, or rapidly, they have spread from dispersal centres.

Some exotic species occur in a wide range of Midlands environments. Particularly widespread are the grasses *Aira caryophyllea*, *Briza minor*, *Holcus lanatus* and *Vulpia bromoides*, and the herbs *Centaurium erythraea*, *Hypochaeris radicata* and *Trifolium dubium*. However, many of the exotic species seem to have strict environmental preferences. For example, *Briza maxima* prefers well-drained non-clayey substrates and *Hypochaeris glabra* is widespread but apparently less frequent in the groups of low-lying habitats. By contrast, *Juncus articulatus* and *Lotus tenuis* occur in those communities associated with depressions, while *Lysimachia nummularia* was only seen growing by streams, where it is particularly prolific. *Agrostis capillaris*, *Anthoxanthum odoratum* and *Filago gallica* did not occur in any of the quadrats that comprise groups 8, 9 and 10. These groups are associated with the lowest rainfall zones, and these three species are probably limited by the frequency of drought in the most extreme Midlands environments.

There are virtually no areas in the Midlands without some naturalised exotic species. While the factors that influence most such species are only poorly understood (Weir 1977 cf. Gleadow 1982, Gleadow & Ashton 1981, Gleadow & Rowan 1982, Gleadow *et al.* 1983 for *Pittosporum undulatum*), the ubiquity of exotic species throughout the Midlands probably reflects the dissected nature of the remnant vegetation and the ready transport of disseminules by a variety of herbivores and machinery.

When the imposed conditions are not detrimental to native vegetation, most exotic species seem to co-exist without causing declines in native species richness (Fensham 1989). This is so for non-woody species in well-drained fertile habitats (Kirkpatrick 1986) and probably also in well-drained infertile substrates in the Midlands, where herbaceous exotic populations appear to be relatively stable. In favourable environments, woody weeds, such as gorse (*Ulex europaeus*) and blackberries (*Rubus fruticosus*) may be capable of invading native vegetation where disturbance phenomena are restricted to those that can be assumed for pre-European conditions. Once established, their ability to form dense thickets excludes native vegetation. The control of these species in the early stages of their invasion is of paramount importance in maintaining the effectiveness of areas of native vegetation for long-term nature conservation.

TABLE 2

Percentage Frequencies of Exotic Species in the Classificatory Groups* of Fensham (1988)

Species†	Community‡													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Juncus articulatus	–	50	57	–	–	–	–	–	–	–	–	–	–	–
Anthoxanthum odoratum	–	50	57	–	7	10	21	–	–	–	–	–	–	–
Agrostis capillaris	–	–	14	–	13	–	29	–	–	–	7	22	–	–
Cynosurus cristatus	–	–	14	–	–	–	–	–	–	–	11	–	–	–
Filago gallica	–	–	–	–	27	10	–	–	–	–	11	–	–	–
Briza maxima	–	–	–	57	17	10	14	–	83	11	–	–	–	–
Aira caryophyllea	67	50	71	78	83	86	79	80	83	83	85	67	–	–
Anagallis arvensis	–	–	43	22	-	14	14	10	-	-	7	22	-	-
Centaurium erythraea	50	100	43	56	47	74	57	25	67	61	56	78	-	-
Vulpia bromoides	67	50	43	-	27	52	29	65	50	39	70	78	-	-
Leontodon taraxacoides	-	-	100	-	10	45	-	35	-	11	30	44	67	100
Trifolium glomeratum	-	-	29	-	-	10	-	75	-	11	30	-	-	-
Hypochaeris glabra	-	-	-	33	27	35	-	55	-	39	33	-	-	-
Romulea rosea	-	-	-	-	-	-	29	10	-	11	-	-	-	-
Hypochaeris radicata	67	100	43	56	57	69	86	75	50	100	70	78	67	100
Briza minor	-	100	57	-	53	76	36	45	-	72	74	56	67	-
Poa annua	-	-	14	-	-	-	-	10	-	-	-	-	67	-
Cerastium fontanum	33	-	-	-	13	-	-	-	33	-	26	22	-	-
Cirsium arvense	67	-	14	-	13	14	14	-	-	11	30	56	100	-
Trifolium dubium	33	50	57	22	10	31	–	70	83	39	57	78	100	–
Rosa rubiginosa	–	–	–	–	–	–	14	15	–	11	7	–	–	–
Ulex europaeus	–	–	14	–	–	–	–	–	–	–	11	–	–	–
Rubus fruticosus	–	–	14	–	–	–	–	–	–	17	11	–	–	–
Trifolium subterraneum	–	–	–	–	–	7	–	20	–	17	19	–	–	–
Cynosurus echinatus	–	–	14	–	–	21	–	50	–	17	11	–	–	–
Holcus lanatus	50	100	57	–	7	10	21	–	50	33	19	78	100	–
Taraxacum officinale	–	–	29	–	–	–	–	–	–	–	–	22	67	100
Agrostis stolonifera	–	50	29	–	–	–	–	–	–	–	4	33	–	–
Linum trigynum	–	–	–	–	–	–	22	–	–	–	7	–	–	–
Hordeum murinum	–	–	–	–	–	–	–	10	–	–	–	–	–	–
Dactylis glomerata	–	–	–	–	–	–	–	10	–	–	–	–	–	–
Geranium dissectum	–	–	–	–	–	–	–	10	–	–	–	–	–	–
Vicia sativa	–	–	–	–	–	–	–	10	–	–	–	–	–	–
Erodium cicutarium	–	–	–	–	–	–	–	20	–	–	–	–	–	–
Lolium perenne	–	–	–	–	–	–	–	30	–	–	–	44	–	–
Plantago lanceolata	–	–	–	–	–	–	–	35	–	22	7	–	–	–
Sonchus asper	–	–	–	–	–	–	–	20	33	–	7	–	–	–
Plantago coronopus	–	–	–	–	–	–	–	25	–	–	14	33	–	–
Rumex acetosella	–	–	–	–	–	–	–	–	50	33	19	–	–	–
Bromus hordeaceus	–	–	–	–	–	17	–	90	50	33	30	33	67	–
Lotus tenuis	–	–	14	–	–	–	–	–	–	–	–	22	–	100
Petrorhagia prolifera	–	–	–	–	–	–	–	50	–	–	19	–	–	–
Silene gallica	–	–	–	–	–	–	–	–	–	11	–	–	–	–
Bromus sterilis	–	–	–	–	–	–	–	40	–	22	11	–	–	–
Carduus tenuiflorus	–	–	–	–	–	–	–	15	50	–	15	–	–	–
Myosotis discolor	–	–	–	–	–	–	–	–	–	–	11	–	–	–
Tragopogon porrifolius	–	–	–	–	–	–	–	–	–	–	7	–	67	–
Lysimachia nummularia	–	–	–	–	–	–	–	–	–	–	–	–	–	100

Notes to Table 2

* Only species with >10% in any group are included.
† Species nomenclature follows Buchanan *et al.* (1989).
‡ (1) *Eucalyptus amygdalina* open forest on dolerite hills. (2) *E. ovata* woodlands on infertile sandy depressions.
(3) Grasslands on moderately fertile sandy depressions. (4) *E. amygdalina* open forest on flat sandy ground.
(5) *E. amygdalina* forest on infertile sands. (6) *E. amygdalina* forest on mixed substrates with moderate rainfall.
(7) *E. amygdalina* forest on mixed substrates with high rainfall. (8) *E. pauciflora* woodland on doleritic clay loams.
(9) *E. pauciflora* woodland on basaltic loams. (10) *E. pauciflora* woodland on sand.
(11) *E. viminalis* woodland on dolerite hills. (12) *E. ovata* woodlands on clayey depressions.
(13) Grasslands on clayey depressions. (14) Grasslands on riverine flats.

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REFERENCES

Belcher, R.O., 1983: New Australian species of Erecthioid *Senecio* (Asteraceae). *Muelleria* 5: 119–122.

Brown, J.M. & Hopkins, A.J.M., 1983: The Kwongan (sclerophyllous shrublands) of Tuttanning nature reserve, W.A. *Aust. J. Ecol.* 8: 63–73.

Brown, M.J., Kirkpatrick, J.B. & Moscal, A., 1983: *AN ATLAS OF TASMANIA'S ENDEMIC FLORA*. Tasmanian Conservation Trust, Hobart.

Buchanan, A.M., McGeary-Brown, A. & Orchard, A.E., 1989: A census of the vascular plants of Tasmania. *Tasm. Herbarium Occ. Pub. No.2.*

Diamond, J.M., 1975: The island dilemma: lessons of modern biogeographic studies for the design of nature reserves. *Biol. Cons.* 7: 129–146.

Dickinson, K.J.M. & Kirkpatrick, J.B., 1986: The impact of grazing in clearfelled, burned and undisturbed eucalypt forest. *Vegetatio* 66: 133–136.

Dimmock, G.M. & Loveday, J., 1953: A survey of the basaltic soils near Campbell Town, Tasmania. *CSIRO Tech. Mem.* 3/53.

Duncan, F. & Brown, M.J., 1985: Dry sclerophyll vegetation in Tasmania, extent and conservation status of the communities. *Wildl. Div. Tech. Rep.* 85/1. National Parks and Wildlife Service, Tasmania.

Fensham, R.J., 1985: The pre-European vegetation of the Midlands in Tasmania. Unpubl. B.Sc. (Hons) thesis, Geog. Dep., Univ. Tasm.

Fensham, R.J., 1989: The pre-European vegetation of the Midlands, Tasmania: a floristic and historical analysis of vegetation patterns. *J. Biogeogr.* 16: 29–45.

Gleadow, R.M., 1982: Invasion by *Pittosporum undulatum* of the forests of central Victoria. II — Dispersal, germination and establishment. *Aust. J. Bot.* 30: 185–198.

Gleadow, R.M. & Ashton, D.H., 1981: Invasion by *Pittosporum undulatum* of the forests of central Victoria. I — Invasion patterns and plant morphology. *Aust. J. Bot.* 29: 705–720.

Gleadow, R.M. & Rowan, K.S., 1982: Invasion by *Pittosporum undulatum* of the forest of Central Victoria. III — Effects of temperature and light on growth and drought resistance. *Aust. J. Bot.* 30: 347–357.

Gleadow, R.M., Rowan, K.S. & Ashton, D.H., 1983: Invasion by *Pittosporum undulatum* of the forests of central Victoria. IV — Shade tolerance. *Aust. J. Bot.* 31: 151–160.

Gunn, R.C., 1842: Remarks on the indigenous vegetable productions available as food for man. *Tasm. J. Nat. Sci.* 1: 35–52.

Hewson, H.J., 1982: Brassicaceae. *In* George, A.S. (Ed.): *FLORA OF AUSTRALIA*. Vol.8. AGPS, Canberra: 231–357.

Higgs, A.J., 1981: Island biogeography theory and nature reserve design. *J. Biogeogr.* 8: 117–124.

Holmes, N.T.H. & Whitton, B.A., 1977: The macrophytic vegetation of the River Tees in 1975: observed and predicted changes. *Freshw. Biol.* 7: 43–60.

Kirkpatrick, J.B., 1977: *THE DISAPPEARING HEATH*. Tasmanian Conservation Trust, Hobart.

Kirkpatrick, J.B., 1986: The viability of bush in cities — Ten years of change in an urban grassy woodland. *Aust. J. Bot.* 34: 691–708.

Kirkpatrick, J.B. & Harwood, C.E., 1983a: Plant communities of Tasmanian wetlands. *Aust. J. Bot.* 31: 437–451.

KIRKPATRICK, J.B. & HARWOOD, C.E., 1983b: Conservation of Tasmanian macrophytic wetland vegetation. *Pap. Proc. R. Soc. Tasm.* 117: 5–20.

KIRKPATRICK, J.B. & TYLER, P.A., 1988: Conservation of Tasmanian wetlands. *In* McComb, A. & Lake, P.S. (Eds): *WETLAND CONSERVATION IN AUSTRALIA*. World Wildlife Fund, Sydney.

KIRKPATRICK, J.B., GILFEDDER, L. & FENSHAM, R.J., 1988: *CITY PARK AND CEMETERIES: TASMANIA'S REMNANT GRASSLANDS AND GRASSY WOODLANDS*. Tasmanian Conservation Trust, Hobart.

LEEPER, G.W., 1952: *INTRODUCTION TO SOIL SCIENCE*. Melbourne University Press.

LEIGH, J., BODEN, R. & BRIGGS, J., 1984: *EXTINCT AND ENDANGERED PLANTS OF AUSTRALIA*. McMillan, Melbourne.

MCDONALD, R.C., ISBELL, R.F., SPEIGHT, J.G., WALKER, J. & HOPKINS, M.S., 1984: *AUSTRALIAN SOIL AND LAND SURVEY. FIELD BOOK*. Inkata Press, Adelaide.

MENADUE, Y. & CROWDEN, R.K., 1985: Three new species of *Ranunculus* (Ranunculaceae) from Tasmania. *Brunonia* 8: 373–380.

MILLAR, J.B., 1973: Vegetation changes in shallow marsh wetlands under improving moisture regime. *Can. J. Bot.* 51: 1443–1457.

RODWAY, L., 1903: *THE TASMANIAN FLORA*. Government Printer, Hobart.

SCARLETT, N.H. & PARSONS, R.F., 1982: Rare plants of the Victorian plains. *In* Groves, R.H. & Ride, W.D.L. (Eds): *SPECIES AT RISK: RESEARCH IN AUSTRALIA*. Australian Academy of Science, Canberra.

SIMBERLOFF, D.S. & ABELE, L.G., 1976: Island biogeography theory and conservation practice. *Science* 191: 285–286.

SPECHT, R.L., 1981: Conservation of vegetation types. *In* Groves, R.H. (Ed.): *AUSTRALIAN VEGETATION*. Cambridge University Press.

SPECHT, R.L. & CLELAND, J.B., 1961: Flora conservation in South Australia. I — The preservation of plant formations and associations recorded in South Australia. *Trans. R. Soc. S. Aust.* 85: 177–197.

SPICER, W.W., 1878: *A HANDBOOK OF THE PLANTS OF TASMANIA*. J. Walch & Sons, Hobart.

STUWE, J. & PARSONS, R.F., 1977: *Themeda australis* grasslands on the Basalt Plains, Victoria: floristics and management effects. *Aust. J. Ecol.* 2: 467–476.

TAYLOR, R.J., 1988: Ecology and conservation of the Tasmanian bettong (*Bettongia gaimardi*). Unpubl. rep. Australian National Parks and Wildlife Service.

WEIR, J.S., 1977: Exotics: Past, present and future. *In* Anderson D. (Ed.): *EXOTIC SPECIES IN AUSTRALIA — THEIR ESTABLISHMENT AND SUCCESS. Proc. Ecol. Soc. Aust.* 10: 4–14.

WILLIAMS, O.B., 1955: Studies in the ecology of the Riverine Plain. I — The gilgai microrelief and associated flora. *Aust. J. Bot.* 3: 99–112.

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APPENDIX

List of Known Midlands Higher Plant Species, showing those presumed to be extinct in the region (*), those unreserved in Tasmania (†)

Numbers refer to references confirming the previous existence of an extinct species.
(1) Spicer (1878)
(2) Rodway (1903)
(3) Hewson (1982)
(4) Belcher (1983)
(5) Leigh *et al.* (1984)
(6) Tasmanian Herbarium
(7) Queen Victoria Museum, Herbarium
(8) Melbourne Herbarium
(9) D. Morris, pers. comm. 1986 (specimen held at Kew Herbarium, London)
(10) A. Buchanan, pers. comm. 1989 (specimen held at N.S.W. Herbarium).
Nomenclature follows Buchanan *et al.* 1989.

PTERIDOPHYTA
ADIANTACEAE
Adiantum aethopicum L.
ASPIDIACEAE
Polystichum proliferum (R.Br.) C. Presl.
ASPLENIACEAE
Asplenium flabellifolium Cav.
AZOLLACEAE
Azolla filiculoides Lam.
BLECHNACEAE
Doodia media R. Br. †
DENNSTAEDTIACEAE
Anogramma leptophylla (L.) Link †
Cheilanthes austrotenuifolia Quirk & Chambers
Hypolepis rugosula (Labill.) J. Smith * 6
Pteridium esculentum (Forst. f.) Nakai
DICKSONIACEAE
Dicksonia antarctica Labill.
ISOETACEAE
Isoetes drummondii A. Braun † * 6
I. elatior F. Muell. †
I. muelleri A. Braun † * 6
MARSILEACEAE
Pilularia novae-hollandiae A.Br. †
OPHIOGLOSSACEAE
Botrychium lunaria (L.) Swartz † * 6
Ophioglossum lusitanicum L.
ssp. *coriaceum* (cunn) Glausen †
SELAGINELLACEAE
Selaginella uliginosa (Labill.) Spring

GYMNOSPERMAE
CUPRESSACEAE
Callitris oblonga A. & L.C. Rich †

ANGIOSPERMAE — MONOCOTYLEDONAE
ALISMATACEAE
Alisma plantago-aquatica L.
CENTROLEPIDACEAE
Aphelia gracilis Sonder †
A. pumilio F. Muell. ex Sonder †
Centrolepis aristata (R.Br.) Roem & Schult.
C. glabra (F. Muell.) Hieron. * 2
C. strigosa (R. Br.) Roem. & Schult.
CYPERACEAE
Baumea arthrophylla (Nees) Boeck.
B. gunnii (Hook. f.) S.T. Blake † * 1,2
Bolboschoenus caldwellii (V. Cook) Sojak
Carex appressa R. Br.
C. bichenoviana Boott † * 6
C. breviculmis R. Br.
C. chlorantha R. Br. * 1,6
C. fascicularis Soland. ex Boott
C. gaudichaudiana Kunth.
C. inversa R. Br. †
C. iynx E. Nelmes
C. tasmanica Kuk. † * 6
C. tereticaulis F. Muell.
Chorizandra cymbaria R. Br.
Cyperus gunnii Hook f.
C. lucidus R. Br. †
C. sanguinolentus Vahl †
C. tenellus L. †
Eleocharis acuta R. Br.
E. pusilla R. Br.
E. sphacelata R. Br.
Gahnia filum (Labill.) F. Muell.
G. grandis S.T. Blake
I. cernua (Vahl.) Roem. & Schult.
I. crassiuscula Hook. f.
I. fluitans (L.) R. Br.
I. hookeriana Boeck
I. inundata R. Br.
I. marginata (Thunb.) A. Dietr.
I. montivaga (S.T. Blake) K.L. Wilson
I. nodosa (Rottb.) R. Br.
I. platycarpa (S.T. Blake) Sojak
I. stellata (C.B. Clarke) K.L. Wilson † * 6
Lepidosperma concavum R. Br.
L. filiforme Labill. * 1
L. laterale R. Br.

L. lineare R. Br.
L. longitudinale Labill.
Schoenoplectus pungens (Vahl) Palla
S. validus (Vahl) A. & D. Love †
Schoenus apogon Roem. & Schult.
S. fluitans L.
S. latelaminatus Kuekenth. †
S. maschalinus Roem. & Schult.
S. nitens (R.Br.) Poir.
S. tesquorum J.M. Black
HYDATELLACEAE
Trithuria submersa Hook. f. † * 2,6
HYDROCHARITACEAE
Vallisneria gigantea Graebner
HYPOXIDACEAE
Hypoxis hygrometrica Labill.
H. vaginata Schldl. †
IRIDACEAE
Diplarrena moraea Labill.
JUNCACEAE
Juncus amabilis Edgar †
J. australis Hook. f.
J. bufonius L.
J. capitatus Weig.
J. filicaulis Buch.
J. holoschoenus R. Br.
J. kraussii Hochst.
J. pallidus R. Br.
J. pauciflorus R. Br.
J. planifolius R. Br.
J. procerus E. Mey.
J. sarophorus L.A.S. Johnson
J. subsecundus N.A. Wakefield
Luzula spp.
JUNCAGINACEAE
Triglochin procera R. Br.
T. striata Ruiz. & Pav.
LEMNACEAE
Lemna disperma Hegelm
L. trisulca L.
Wolffia australiana (Benth.) Hartog and Plas. †
LILIACEAE
Arthropodium milleflorum (DC.) Macbride
A. minus R. Br.
Bulbine glauca (Raf.) E.M. Watson
Burchardia umbellata R. Br.
Caesia parviflora R. Br.
var. *parviflora*
var. *vittata* (R. Br.) R. Henderson †
Chaemaescilla corymbosa (R. Br.) F. Muell. ex Benth.
Dianella longifolia R. Br. †
D. tasmanica Hook. f.
Dichopogon strictus (R. Br.) Baker
Thysanotus patersonii R. Br.
Tricoryne elatior R. Br.
Wurmbea dioica (R. Br.) F. Muell.
ORCHIDACEAE
Caladenia catenata (Sm.) Druce
C. caudata W.H. Nicholls
C. clavigera A. Cunn ex Lindley †
C. cucullata FitzG.
C. pattersonii R. Br.
Calochilus imberbis R.S. Rogers †
C. gunnii Lindley * 6
C. reflexa (Labill.) Druce * 6
Corybas incurvus D. Jones & M. Clements † * 6
Dipodium punctatum (Smith) R. Br.
Diurus maculata Smith
D. sulphurea R. Br. * 6
Eriochilus cucullatus (Labill.) Reichb. f.
Glossodia major R. Br.
Microtis unifolia (Forst. f.) Reichb. f.
Prasophyllum odoratum R.S. Rogers † * 6
Pterosylis biseta J.A. Blackmore & Clemesha †
P. curta R. Br.
P. furcata Lindley * 6
P. mutica R. Br. * 6
P. pedunculata R. Br.
P. rufa R. Br.
Spiranthes sinensis (Pers.) Ames * 1
Thelymitra aristata Lindley * 6
T. carnea R. Br.
T. megcalyptra R.D. FitzG.
T. pauciflora R. Br.
POACEAE
Agrostis aemula R. Br.
A. avenacea J.F. Gmel.
A. billardieri R. Br.
A. venusta Trin.
Amphibromus archeri (J.D. Hook.) P.F. Morris
A. macrorhinus S.W.L. Jacobs & L. Lapinpuro †
A. neesii Steud. †
A. recurvatus Swallen
A. sinuatus S.W.L. Jacobs & L. Lapinpuro †
Danthonia caespitosa Gaudich.
D. carphoides F. Muell. ex Benth.
var. *angustior* Vickery †
D. dimidiata Vickery
D. laevis J.W. Vickery
D. penicillata (Labill.) P. Beauv.
D. pilosa R. Br.
D. popinensis D.I. Morris †
D. procera Vickery †
D. racemosa R. Br.
D. semiannularis (Labill.) R. Br.
D. setacea R. Br.
D. tenuior (Steudel) Conert
Deyeuxia lawrencii Vickery † * 9
D. quadriseta Benth.

Dichelachne crinita Hook.
D. rara (R. Br.) Vickery
Distichlis distichophylla (Labill.) Fassett
Echinopogon ovatus (G. Foster) P. Beauv.
Elymus scabrus (Labill.) A. Love
Eragrostis molybdea Vic. †
Ehrharta acuminata (R. Br.) Sprengel * 1
E. distichophylla Labill.
E. stipoides Labill.
Festuca plebeia R. Br.
F. hookeriana F. Muell. ex J.D. Hook. * 1
Glyceria australis C.E. Hubb
Hemarthria uncinata R. Br.
Pentapogon quadrifidus Baill.
Phragmites australis (Cav.) Trin. ex Steudel
Poa hookeri Vick. †
P. labillardieri Steud.
P. mollis Vick. †
P. pratermissa D.I. Morris †
P. rodwayi Vickery
P. sieberiana Spreng.
Puccinellia stricta (Hook. f.) C. Blom
Stipa bigeniculata Hughes
S. mollis R. Br.
S. nodosa S.T. Blake
S. pubinodis Trinius & Rupecht
S. rudis Sprengel
ssp. *australis* J. Everett & S. Jacobs
S. scabra Lindley †
S. semibarbata R. Br.
S. stuposa D.K. Hughes
Themeda triandra Forsskal
Zoysia macrantha Desv.

POTAMOGETONACEAE
Potamogeton australiensis A. Bennett
P. crispus L.
P. ochreatus Raoul †
P. pectinatus L. †
P. perfoliatus L. †
P. tricarinatus F. Muell. & A. Bennett ex A. Bennett

RESTIONACEAE
Leptocarpus brownii Hook. f.
Lepyrodia muelleri Benth.

RUPPIACEAE
Ruppia maritima L.

TYPHACEAE
Typha domingensis Pers.
T. latifolia L.

XANTHORRHOEACEAE
Lomandra nana (A. Lee) A. Lee †
L. longifolia Labill.

ZANNICHELLIACEAE
Lepilaena cylindrocarpa (Kornicke) Benth.
L. preissii (Lehm.) F. Muell. † * 2

ANGIOSPERMAE — DICOTYLEDONS

AMARANTHACEAE
Alternanthera denticulata R. Br. † * 7
Ptilotus spathulatus (R. Br.) Poir. †

APIACEAE
Apium prostratum Labill. ex Vent.
Centella cordifolia (Hook. f.) Nannfeldt
Daucus glochidiatus (Labill.) Fisch. et al.
Eryngium vesiculosum Labill.
Hydrocotyle callicarpa Bunge
H. muscosa R. Br.
H. sibthorpioides Lamk.
Lilaeopsis polyantha (Gand.) H. Eichler
Trachymene humilis (Hook. f.) Benth. †

ASTERACEAE
Angianthus preissianus (Steetz) Benth.
Bedfordia salicina (Labill.) DC.
Brachyscome aculeata (Labill.) Less.
B. angustifolia A. Cunn. ex DC. * 6
B. cardiocarpa F. Muell. ex Benth.
B. decipiens Hook. f. * 6
B. radicans Steetz in Lehm. †
B. rigidula (DC.) G.L. Davis †
B. spathulata Gaud.
Calocephalus lacteus Lessing †
Centipeda minima (L.) A. Br. & Aschers.
Cotula australis (Sieber ex Spreng.) Hook. f. * 6
C. coronopifolia L.
C. reptans (Benth.) Benth.
Craspedia glauca (Labill.) Spreng.
Craspedia sp. "Tunbridge" †
Cymbonotus lawsonianus Gaudich.
Gnaphalium collinum Labill.
G. involucratum Forst. f.
G. purpureum L.
Helichrysum apiculatum (Labill.) D. Don.
H. bicolor Lindl.
H. dendroideum N.A. Wakefield
H. scorpioides Labill.
H. semipapposum (Labill.) DC.
H. aff. *semipapposum* "Launceston" †
H. thyrsoideum (DC) P. Morris & J.H. Willis * 6
Helipterum albicans (A. Gunn) DC.
var. *incanum* (Hook.) P.G. Wilson †
H. anthemioides (Sieber ex Spreng.) DC. † * 6
H. australe (A. Gray) Druce †
H. demissum (A. Gray) Druce †
Isoetopsis graminifolia Trucz. †
Lagenifera huegelii Benth. * 9
L. stipitata (Labill.) Druce
Leptorhynchos elongatus DC. * † 2,6
L. linearis Lessing
L. squamatus (Labill.) Lessing
Microseris lanceolata (Walp.) Schultz-Bip.
Millotia tenuifolia Cass. =

Olearia argophylla (Labill.) Benth.
O. ciliata (Benth.) F. Muell. ex Benth. * 1
O. floribunda (Hook. f.) Benth.
O. ramulosa (Labill.) Benth.
O. stellulata (Labill.) DC.
O. viscosa (Labill.) Benth.
Podolepis jaceoides (Sims) Voss
Pseudognaphalium luteo-album (L.) Hilliard & B.L. Burtt.
Senecio glomeratus Desf. ex Poir.
S. hispidulus A. Rich.
S. macrocarpus Belcher † * 4
S. quadridentatus Labill.
Solenogyne dominii L. Adams
S. gunnii (Hook. f.) Carbrera
Vittadinia cuneata DC. †
V. gracilis (Hook. f.) N. Burb. †
V. muelleri N. Burb. †

BORAGINACEAE
Cynoglossum australe R. Br.
C. suaveolens R. Br.
Myosotis australis R. Br.

BRASSICACEAE
Barbarea australis J.D. Hook. † * 3
Cardamine tenuifolia Hook.
Hymenolobus procumbens (L.) Nutt. ex Schinz. & Thell. * 1
Lepidium pseudotasmanicum Thell. †
Rorippa dictyosperma (Hook.) L. Johnson

BRUNONIACEAE
Brunonia australis Smith ex R. Br. †

CALLITRICHACEAE
Callitriche umbonata Hegelm. †

CAMPANULACEAE
Isotoma fluviatilis (R. Br.) F. Muell. ex Benth. *
Lobelia alata Labill.
L. gibbosa Labill.
L. pratioides Benth. † * 1,6
L. rhombifolia deVriese † * 5
Pratia pedunculata (R. Br.) Benth. †
Wahlenbergia gracilenta N. Lothian
W. gracilis (Forst. f.) Schrader
W. gymnoclada N. Lothian
W. multicaulis Benth.
W. stricta Sweet

CARYOPHYLLACEAE
Colobanthus apetalus (Labill.) Druce * 8
C. aff. *strictus*
Scleranthus biflorus (Forst. & Forst. f.) Hook. f.
S. diander R. Br. †
Spergularia media (L.) Cyrillo
Stellaria flaccida Hook.

CASUARINACEAE
Allocasuarina littoralis (Salisb.) L. Johnson
A. verticillata (Lam.) L. Johnson

CHENOPODIACEAE
Chenopodium glaucum L.
C. pumilio R. Br. † * 6
Einadia nutans (R. Br.) A.J. Scott

CLUSIACEAE
Hypericum gramineum Forst. f.
H. japonicum Thunb.

CONVOLVULACEAE
Convolvulus erubescens Sims
Dichondra repens Forst. & Forst. f.
Wilsonia rotundifolia Hook. †

CRASSULACEAE
Crassula helmsii (Kirk) Cockayne
C. peduncularis (SMith) Meigen * 6
C. sieberana (Schult. & Schult. f.) Druce

DILLENIACEAE
Hibbertia hirsuta (Hook.) Benth.
H. prostrata Hook
H. riparia (R. Br. ex DC.) Hoogl.
H. serpyllifolia R. Br. ex DC.

DROSERACEAE
Drossera peltata Thunb.
ssp. *auriculata* (Backh. ex Planchon) Conn
ssp. *peltata*
D. pygmaea DC.

ELATINACEAE
Elatine gratioloides A. Cunn.

EPACRIDACEAE
Acrotriche serrulata (Labill.) R. Br.
Astroloma humifusum (Cav.) R. Br.
Brachyloma ciliatum (R. Br.) Benth.
Cyathodes parvifolia
Epacris excerta R. Br. †
E. impressa Labill.
Leucopogon collinus (Labill.) R. Br.
L. virgatus (Labill.) R. Br.
Lissanthe strigosa (Sm.) R. Br.
Styphelia adscendens R. Br.

EUPHORBIACEAE
Amperea xiphoclada (Sieber ex Spreng.) Druce
Bertya rosmarinifolia Planch. † * 1,2
Beyeria viscosa (Labill.) Miq.
Micrantheum hexandrum Hook. f. †
Phyllanthus australis Hook. f.
Poranthera microphylla Brongn.

FABACEAE
Acacia axillaris Benth. †
A. dealbata Link
A. genistifolia Link
A. gunnii Benth.
A. mearnsi De Wild
A. melanoxylon R. Br.
A. mucronata Willd. ex Wendl.
A. siculiformis A. Cunn. ex Benth. * 1
A. verticillata (L'Herit.) Willd.

Aotus ericoides (Vent.) G. Don
Bossiaea cinerea R. Br.
B. prostrata R. Br.
B. riparia A. Cunn. ex Benth.
Daviesia latifolia R. Br.
D. ulicifolia Andr.
Desmodium varians var. *gunnii* (Hook. f.) Benth. † * 6
Dillwynia cinerascens R. Br.
Glycine latrobeana (Meissn.) Benth. = *Gompholobium huegelii* Benth.
Hovea lanceolata Sims
H. linearis (Smith) R. Br.
Indigofera australis Willd.
Kennedia prostrata R. Br.
Platylobium obtusangulum Hook.
Pultenaea fasciculata Benth.
P. humilis Benth. ex Hook. f. †
P. juniperina Labill.
P. prostrata Benth. ex Hook. f. †

GENTIANACEAE
Sebaea ovata (Labill.) R. Br.

GERANIACEAE
Geranium sessiliflorum Cav. ssp. *brevicaule* (Hook. f.) R.C. Carolin
G. solanderi R.C. Carolin
Pelargonium australe Willd.

GOODENEACEAE
Goodenia amplexans F. Muell. † * 2,8
G. elongata Labill.
G. humilis R. Br.
G. lanata R. Br.
G. ovata Sm.
Selliera radicans Cav.
Velleia paradoxa R. Br. †

HALORAGACEAE
Gonocarpus micranthus Thunb.
G. tetragynus Labill.
Haloragis aspera Lindley †
Myriophyllum glomeratum Schindler † * 8
M. integrifolium (Hook. f.) Hook. f.
M. pedunculatum Hook. f.
M. salsugineum Orch.
M. simulans Orch.
M. variifolium Hook. f.

LAMIACEAE
Ajuga australis R. Br.
Mentha diemenica Spreng.
Prostanthera cuneata Benth. * 2,6,7
P. rotundifolia R. Br.
Prunella vulgaris L.
Teucrium corymbosum R. Br.
Westringia rubiaefolia R. Br.

LENTIBULARIACEAE
Utricularia australis R. Br. * 1
U. dichotoma Labill.
U. monanthos Hook. f.

LAURACEAE
Cassytha pubescens R. Br.

LINACEAE
Linum marginale A. Cunn. ex Planchon

LYTHRACEAE
Lythrum hyssopifolia L.

MALVACEAE
Asterotrichion discolor (Hook.) Melville
Lawrencia spicata Hook.

MENYANTHACEAE
Villarsia reniformis R. Br.

MYRTACEAE
Baeckea ramosissima A. Cunn.
Callistemon pallidus (Bonpl.) DC.
C. viridiflorus (Sims) Sweet
Calytrix tetragona Labill.
Eucalyptus amygdalina Labill.
E. obliqua Labill.
E. ovata Labill.
E. pauciflora Sieber ex Spreng.
E. rodwayi R.T. Bak. & H.T. Smith
E. rubida H. Deane & Maiden †
E. viminalis Labill.
Leptospermum lanigerum (Ait.) Sm.
L. scoparium Forst. & Forst. f.
Melaleuca ericifolia Sm.
M. gibbosa Labill.

OLEACEAE
Notelaea ligustrina Vent.

ONAGRACEAE
Epilobium billardierianum Ser. ex DC.

OXALIDACEAE
Oxalis perennans Haw.

PITTOSPORACEAE
Billardiera procumbens (Hook.) E. Bennett
B. scandens Sm.
Bursaria spinosa Cav.
Pittosporum bicolor Hook.

PLANTAGINACEAE
Plantago antarctica Dcne. †
P. varia R. Br.

POLYGALACEAE
Comesperma volubile Labill.

POLYGONACEAE
Muehlenbeckia axillaris (Hook. f.) Walp.
Persicaria hydropiper (L.) Opiz.
Polygonum decipiens R. Br. † * 6
Rumex brownii Campd.
R. dumosis A. Cunn. ex Meissn. †

PORTULACACEAE
Montia australasica (Hook. f.) Pax & Hoffm.

PRIMULACEAE
Samolus repens (Forst. & Forst. f.) Pers.

PROTEACEAE
Banksia marginata Cav.
Grevillea australis R. Br.
Hakea lissosperma R. Br.
H. microcarpa R. Br.
Lomatia tinctoria (Labill.) R. Br.
Persoonia juniperina Labill.
RANUNCULACEAE
Clematis aristata R. Br.
C. gentianoides DC.
C. microphylla DC.
Ranunculus decurvus (Hook. f.) Melville * 6
R. glabrifolius Hook.
R. lappaceus Sm.
R. pimpinellifolius Hook. * 6
R. prasinus (Menadue & Crowden) †
R. trichophyllus Chaix
RHAMNACEAE
Cryptandra amara Sm. †
Discaria pubescens (Brongn.) Druce † * 6
Pomaderris elliptica sens. Ewart
Spyridium ulicinum (Hook.) Benth.
S. vexilliferum (Hook.) Reiss.
Stenanthemum pimeleoides (Hook. f.) Benth.
ROSACEAE
Acaena agnipila Gand.
var. *tenuiscarpa* (Bitt.) Orch. †
A. echinata Nees
A. novae-zelandiae Kirk
A. ovina A. Cunn.
Rubus parvifolius L.
RUBIACEAE
Asperula conferta Hook. f.
A. scoparia Hook. f. † * 6
A. subsimplex Hook. f. † * 6
Coprosma quadrifida (Labill.) Robinson
Galium australe DC.
G. ciliare Hook. f.
G. gaudichaudii DC.
Opercularia ovata Hook. f.
O. varia Hook. f.
RUTACEAE
Eriostemon verrucosus A. Rich.
Phebalium squameum (Labill.) Engl.
ssp. *retusum* (Hook.) P.G. Wilson †
SANTALACEAE
Exocarpos curpessiformis Labill.
E. strictus R. Br.
Leptomeria drupacea (Labill.) Druce
SAPINDACEAE
Dodonaea filiformis Link
D. viscosa (L.) N.J. Jacq.
SCROPHULARIACEAE
Euphrasia scabra R. Br. † * 5
Glossostigma elantinoides (Benth.) ex Hook. f. * 2
Gratiola latifolia R. Br. * 6
G. nana Benth.
Limosella australis R. Br.
Mazus pumilio R. Br.
Mimulus repens R. Br.
Parahebe derwentiana (Andrews) B. Briggs &
Ehrend. † * 6
Veronica calycina R. Br.
V. formosa R. Br.
V. gracilis R. Br.
V. scutellata L. †
SOLANACEAE
Solanum nigrum L.
STACKHOUSIACEAE
Stackhousia gunnii Hook. f. †
S. monogyna Labill.
STYLIDIACEAE
Stylidium graminifolium Rich.
THYMELEACEAE
Pimelea curviflora R. Br. †
P. glauca R. Br.
P. humilis R. Br.
P. nivea Labill.
P. pauciflora R. Br. †
TREMANDRACEAE
Tetratheca pilosa Labill. * 6
T. procumbens Gunn ex Hook. f.
VIOLACEAE
Hymenanthera dentata R. Br. ex DC.
Viola betonicifolia Sm.
V. hederacea Labill.

A TRANSECT STUDY OF THE SAND DUNE VEGETATION AT BAKERS BEACH, TASMANIA

by M. A. Chladil and J. B. Kirkpatrick

(with three tables, five text-figures and three plates)

CHLADIL, M.A. & KIRKPATRICK, J.B., 1989 (31:x): A transect study of the sand dune vegetation at Bakers Beach, Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 247–256. ISSN 0080–4703. Department of Geography and Environmental Studies, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001.

Vegetation zonation on coastal sand dunes at Bakers Beach consists of *Spinifex hirsutus* grassland, *Helichrysum paralium-Acacia sophorae* heath and a complex of *Acacia sophorae* heath with *Lomandra longifolia* herbland, the latter community being concentrated in the swales. *Melaleuca ericifolia* swamp forest occupies the drainage line to the rear of the sand dunes. Although the two seaward zones and the swamp forest may be in equilibrium with the environmental complex, the vegetation on the main body of the dunes has been degraded from its original state by clearing and stock grazing and shows evidence of shifting from its present condition towards communities dominated by *Leucopogon parviflorus* and *Banksia marginata*. *Eucalyptus viminalis* open-forest may have occupied much of this dune system in the past. Floristic variation along a transect through the dunes is closely related to edaphic and topographic conditions, supporting models of soil–vegetation relationships on sand dune systems that have been developed elsewhere in southeastern Australia.

Key Words: coastal vegetation, sand dunes, Tasmania.

INTRODUCTION

Some quantitative data are available on the vegetation of coastal sand dune sequences in southeastern Tasmania (Bowden & Kirkpatrick 1974, Brown & Bayley-Stark 1979, Kirkpatrick, in press) and southeastern Australia (Turner *et al.* 1962, Specht 1972, Ladd *et al.* 1976, Barson & Calder 1981, Kirkpatrick, in press) but none are available for northern Tasmania. Other Tasmanian coastal areas have also been described (Stephens & Cane 1939, Davis 1940, Kirkpatrick 1973, 1975, Brown 1980). As northern Tasmania was known to largely lack plant communities and species such as *Leptospermum laevigatum* and *Banksia integrifolia* that characterise sand dune systems of the humid southeastern Australian mainland (Kirkpatrick, in press), and was also known to have beach sands which are considerably more calcareous than those of southeastern Tasmania (Davies 1978), it was thought worthwhile to document the vegetation of one of its largest systems of parallel dunes, or beach ridges (Davies 1978) at Bakers Beach in Asbestos Range National Park (fig. 1). The study was conducted in May, August and September 1986. The pattern of variation in vegetation along a transect orthogonal to the beach is described, and the relationship between edaphic and topographic environmental variables and vegetation along this transect is examined. The past and likely future of the vegetation of this sand dune system are discussed.

THE STUDY AREA

Bakers Beach (41°08'S 146°38'E) faces Bass Strait on Tasmania's mid-northern coast at the mouth of the Port Sorell estuary (fig. 1). The beach front is about 7 km long and has a dune system parallel to the beach front with a lagoon and wetlands behind.

The beach is located within Asbestos Range National Park (4281 ha) which was proclaimed in 1976. Prior to proclamation, the Park was mostly a grazing property; the lagoon and wetlands had been drained for improved pasture and the whole area subject to recurrent fires for "green pick" and to wildfires. Following proclamation, grazing stock were removed and the (convict built) drains filled. As the lagoon filled, the native animal population rapidly expanded. A wildfire burnt much of the dune system in 1978. The vegetation is recovering from the fire in the face of heavy grazing pressure from European rabbit (*Oryctolagus cuniculus*), common wombat (*Vombatus ursinus*) and Bennetts wallaby (*Macropus rufogriseus*).

The study area experiences a temperate maritime climate (National Parks & Wildlife Service

FIG. 1 — Location map.

TABLE 1

Selected Average Climatic Data for Low Head, Tasmania (28 m a.s.l.)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Rainfall (mm)	37	38	42	55	68	80	80	71	60	60	41	46	683
Maximum temperature (°C)	20.0	20.4	19.1	16.8	14.3	12.3	11.7	12.1	13.2	14.6	16.6	18.5	15.8
Minimum temperature (°C)	12.7	13.1	12.0	10.2	8.2	6.5	5.9	6.3	7.4	8.5	10.0	11.6	9.4

Source: Bureau of Meteorology, 1979.

(NPWS) 1979). The nearest weather station is at Low Head 16 km to the east. The annual rainfall is likely to be in the range 650–750 mm, mostly falling in winter. Temperatures are mild, with a range at Low Head of 12.7°C to 20°C in January and 5.9°C to 11.7°C in July. Selected data are presented in table 1 (Bureau of Meteorology 1979).

The wind regime has close to a bimodal distribution: dry northwesterlies (mostly in summer) and moist southwesterlies (mostly in winter). The major fetch is to the west-northwest, making Bakers Beach a relatively high-energy part of the coast.

METHODS

At 25 sites located on dune ridges and swales along a surveyed transect placed orthogonally to the beach (fig. 1) the following data were collected: the percentage cover of all perceived higher plant species, moss and bare sand along 20 m line intercepts (Canfield 1941) laid along dune swales and ridges; soil horizon depth; pH (using a CSIRO soil-testing kit); Munsell colour; and depth of water table, where less than 2 m. Soils were collected for later analysis of $CaCO_3$, and organic matter content.

The qualitative vegetation data were classified using the polythetic divisive technique contained in the program TWINSPAN (Hill 1979) and were ordinated using detrended correspondence analysis (Hill & Gauch 1980). Product moment correlation coefficients were used to test relationships between vegetation and environment. Swamp vegetation sites were excluded from some analyses.

Species nomenclature follows Curtis (1963, 1967), Curtis & Morris (1975) and Willis (1970) except where authorities are given at first mention. Structural nomenclature follows Kirkpatrick & Harwood (1983) for wetland communities and Specht (1970) for other communities.

RESULTS AND DISCUSSION

Variation along the Transect

Calcareous sands undifferentiated to depth characterise the two foremost dunes (table 2), the second of which is the tallest in the whole series (12.5 m). On these two dunes vegetation changes from *Cakile* ephemeral herbland at the rear of the beach to heavily-grazed *Spinifex hirsutus* open-grassland on the small foredune to a rich mixture of composite shrubs, scramblers (*Tetragonia implexicoma* and *Rhagodia baccata*) and *Acacia sophorae* on the second large dune (fig. 2, pl. 1).

The smaller ridges and swales to the rear of the foredune system have been topdressed by calcareous sands as a result of blowouts on the foredune. This narrow layer of calcareous sand is underlain by one, or sometimes two, weakly podsolised soil horizons. In this part of the dune system, swales are largely occupied by *Pteridium*

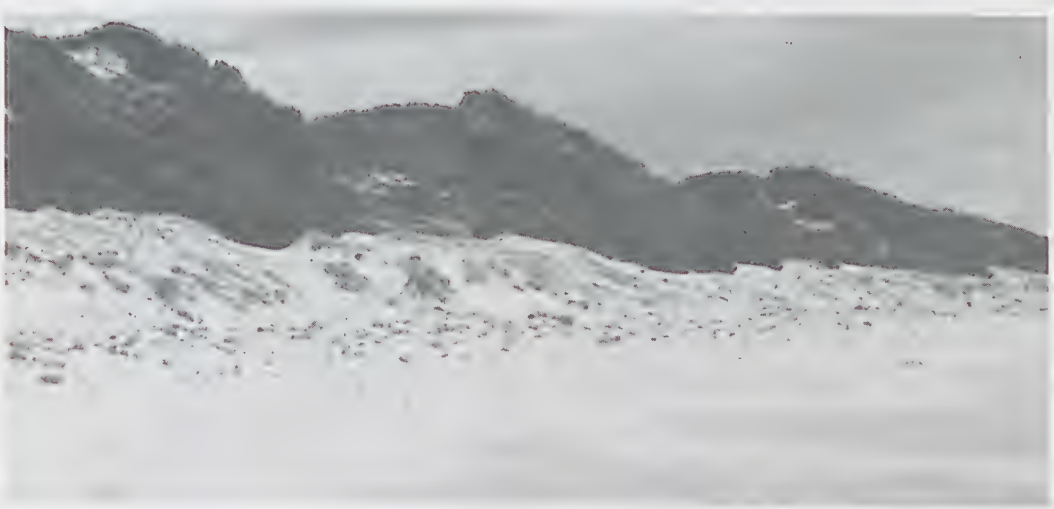

PLATE 1
The foredune at Bakers Beach showing ephemeral herbland, grassland and scrub.

PLATE 2
Ridges dominated by Acacia sophorae *and swale dominated by* Lomandra longifolia.

TABLE 2

Surface Soil Properties Along the Transect at Bakers Beach

Sample*	$CaCO_3$ %	pH	NaCl (ppm)	Organic content %
D1	10.45	7.0	70	0.0
D2	12.36	7.0	14.5	0.0
D3	13.78	7.0	4	0.0
D4	6.75	7.0	14	0.0
D5	6.95	7.0	45	0.0
R1	8.42	7.0	6.5	0.0
S1	9.21	7.0	11	0.0
R2	8.99	8.0	5.5	0.0
S2	7.33	7.0	6	0.0
R3	8.19	7.0	16	1.9
S3	6.37	7.0	0	0.0
R4	5.69	6.5	12	1.3
S4	4.22	7.0	4	0.5
R5	5.06	6.5	34.5	1.5
S5	3.22	6.0	16.5	1.4
R6	4.45	6.0	18	1.0
S6	5.00	6.0	39.5	3.4
R7	3.34	6.0	22	1.5
S7	3.18	6.0	7	3.7
R8	2.80	6.0	3.5	2.3
M	2.41	6.0	40	2.6
E	5.82	6.0	11	1.6

* Swamp samples excluded

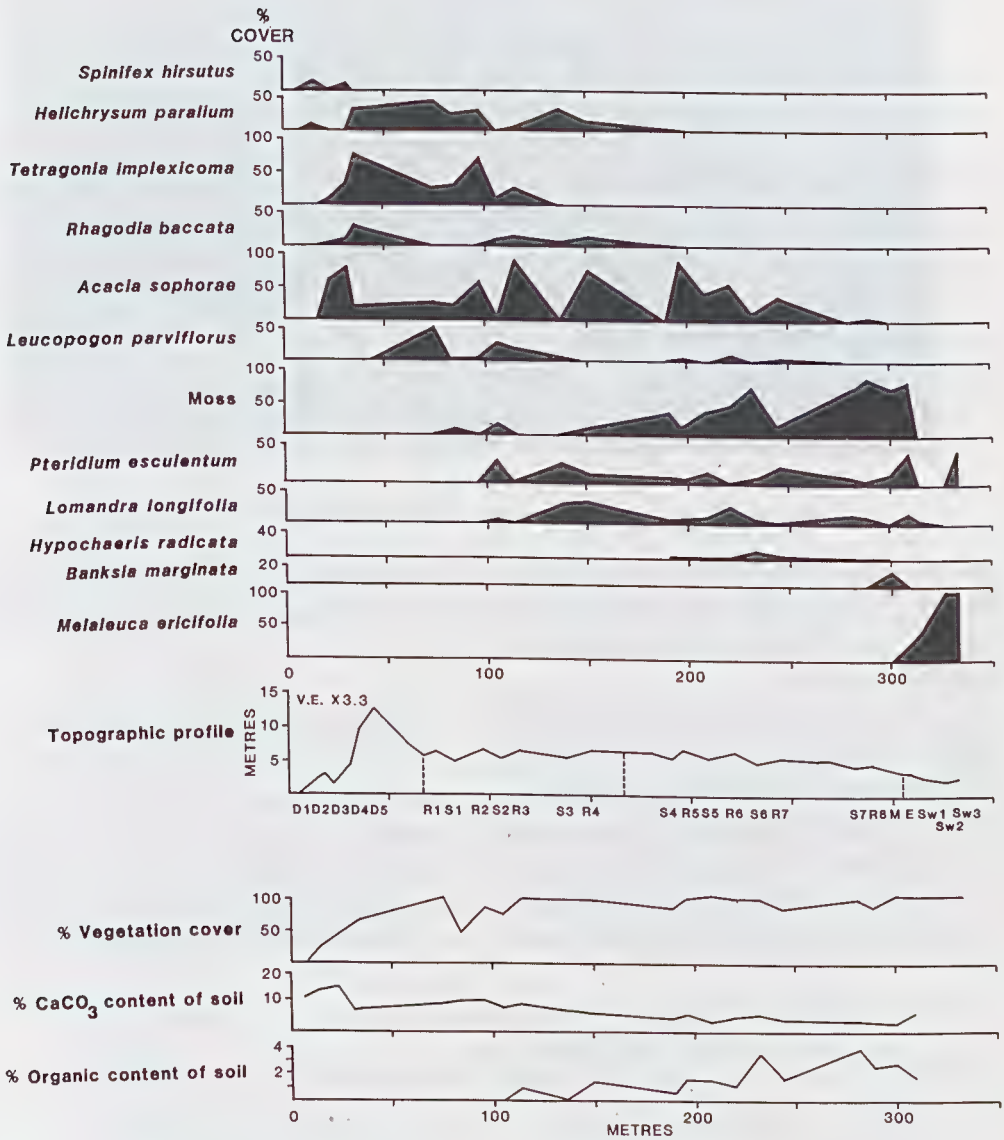

FIG. 2 — Percentage cover of selected species and variability in environmental attributes over the transect.

PLATE 3
The rear of the sand dune system, the swamp and the stranded cliff.

esculentum, *Lomandra longifolia*, small herbs and bare sand, while the ridges have vegetation similar to that of the second foredune with scramblers among composite shrubs and 1–2 m tall spreading *Acacia sophorae* (pl. 2).

The break between topdressed podsols and those without topdressing can be clearly perceived in the absence of scramblers and composite shrubs, in the presence of species such as *Acaena echinata* and *Pimelea humilis* and in the increased cover of moss (fig. 2, pl. 2). The rear dunes have the same pattern of shrub dominance on ridges and herb dominance in swales as is evident for the topdressed area (pl. 3). They are bounded by a swale with a species-poor 10 m tall *Melaleuca ericifolia* swamp forest to their rear. This forest abuts a quartzite cliff covered by scrub dominated by *Casuarina stricta* on its lower slopes and heath on its upper slopes (pl. 3).

Vegetation–Environment Relationships along the Transect

TWINSPAN classification clearly discriminated between the major vegetation units described above, and also between vegetation ridges and swales on the old sand at the rear of the sand dune system (table 3, fig. 3). The ordination scores on the first axis exhibit an exponential decline with

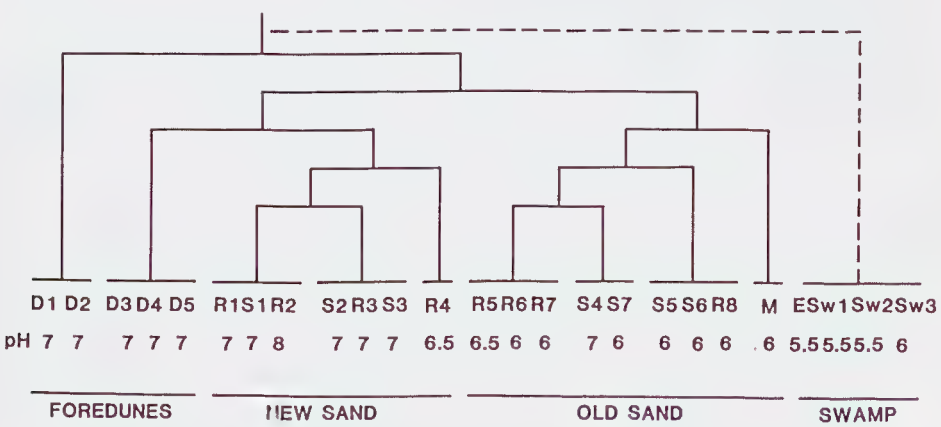
D1 D2 D3 D4 D5 R1 S1 R2 S2 R3 S3 R4 R5 R6 R7 S4 S7 S5 S6 R8 M ESw1 Sw2 Sw3
pH 7 7 7 7 7 7 7 8 7 7 7 6.5 6.5 6 6 7 6 6 6 6 .6 5.5 5.5 5.5 6
FOREDUNES
NEW SAND
OLD SAND
SWAMP

FIG. 3 — TWINSPAN classification of samples as related to pH and environment.

TABLE 3

Percentage Frequency of Species by TWINSPAN Classification Groups

Species	Colonisers (n=5)	New sand (n=7)	Old sand (n=9)	Swamp (n=4)
Spinifex hirsutus	100	–	–	–
Cakile edentula	20	–	–	–
Helichrysum paralium	60	86	11	–
Acacia sophorae	60	86	67	–
Tetragonia implexicoma	60	71	–	–
Rhagodia baccata	60	71	–	–
Acaena novae-zelandiae	20	–	–	–
Oxalis corniculata	20	100	67	25
Fumaria sp.	20	86	33	–
Leucopogon parviflorus	20	71	56	50
Stipa flavescens	20	29	–	–
Carpobrotus rossii	40	86	78	–
Pteridium esculentum	–	100	100	50
Lepidosperma gladiatum	–	29	–	–
Dichondra repens	–	86	56	25
Graminae sp.	–	57	22	–
Senecio minimus	–	57	–	–
Lomandra longifolia	–	71	100	50
Clematis microphylla	–	14	22	–
Danthonia setacea	–	14	78	–
*Hypochaeris radicata**	–	–	100	–
Coprosma quadrifida	–	–	22	–
Acaena echinata	–	–	78	25
Pimelea humilis	–	–	78	25
Luzula sp.	–	–	56	–
Acrotriche serrulata	–	–	44	25
Geranium sessiliflorum	–	–	89	25
Cymbonotus lawsonianus	–	–	11	–
Plantago varia	–	–	33	–
Helichrysum scorpioides	–	–	11	–
Aira sp.	–	–	56	25
Banksia marginata	–	–	22	–
*Rumex acetosella**	–	–	44	25
Dichelachne crinita	–	–	11	–
Melaleuca ericifolia	–	–	11	100
Scleranthus biflorus	–	–	11	–
Carex sp.	–	–	11	–
Centaurium sp.*	–	–	11	–
Glycine clandestina	–	–	11	–
Exocarpus strictus	–	–	11	–
Leptospermum lanigerum	–	–	–	25
Acacia verticillata	–	–	–	50
Helichrysum dendroideum	–	–	–	25
Rubus parvifolius	–	–	–	25
Cassytha melantha	–	–	–	25
Bursaria spinosa	–	–	–	25
Moss sp.	–	100	100	25
Fungi sp.	20	14	–	50
Litter	–	14	56	–
Lichen sp.	–	14	11	–

* exotic species

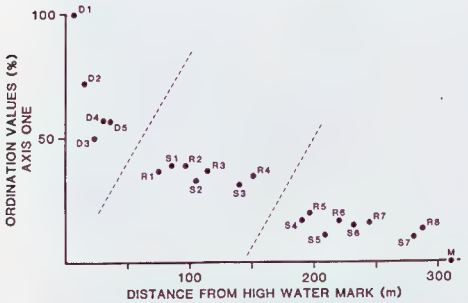

FIG. 4 — Relationship between ordination scores on axis one and distance from the high water mark.

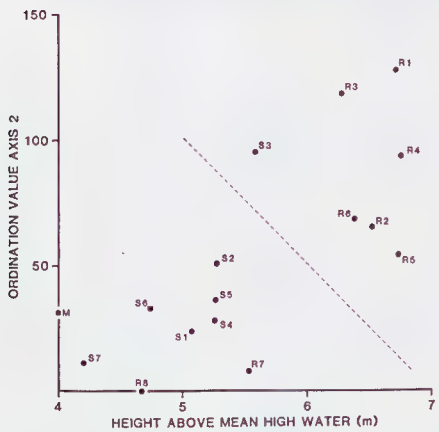

FIG. 5 — Relationship between ordination values on axis two and height above mean high tide mark.

distance inland (fig. 4). The natural logarithm of the distance inland along the transect is highly correlated with cumulative species number ($r = 0.945$ $p < 0.001$). Salt spray deposition is a power function of distance inland (Ranwell 1972), suggesting that the major influence on species occurrence might be exposure to salt spray. However, edaphic variation is also strongly directional. Ordination scores on the first axis are not as strongly correlated with surface pH, soil organic content or calcium carbonate content as with the natural logarithm of distance inland ($r = 0.55$ $p < 0.01$, $r = -0.66$ $p < 0.001$, and $r = -0.798$ $p < 0.001$, cf. $r = -0.958$ $p < 0.001$). However, soil nutrient conditions cannot be dismissed as a major influence on directional vegetation change, especially given the sharp break in species distribution patterns at the new sand–old sand boundary in the ridge/swale complex. The proportion of bare ground, and thus potentially mobile sand, may be important in limiting species establishment (Ranwell 1972: 51). The correlation coefficient between sand cover and the cumulative species number ($r = -0.843$ $p < 0.01$) is consistent with this hypothesis.

The second axis of the ordination is most closely related to topography, as indicated by height above the mean high-water mark. All sites in the ridge/swale complex above 5.6 m have ordination scores in excess of 51, while all such sites below 5.6 m have ordination scores less than this figure (fig. 5). Height above sea level is probably related to moisture availability in the upper part of the soil. This hypothesis is supported by the relationship between moss cover and height above sea level in the ridge/swale complex ($r = -0.720$, $p < 0.001$). Consistent moisture availability and occasional waterlogged conditions are almost certainly associated with the *M. ericifolia* swamp forest, the only place where the water table is reached within 2 m.

Vegetation Change

Buried soil horizons and dune morphology indicate that the sand dune system was dynamic even before European settlement. The vegetation undoubtedly responded to such changes and to past variations in Aboriginal land use.

There is no direct evidence of the nature of the Bakers Beach dune vegetation before 1800. The remains of dead *Eucalyptus viminalis*, and some living individuals of *Casuarina stricta*, *Bursaria spinosa* and *Banksia marginata* indicate that communities dominated by trees could potentially occupy most of the ridge/swale complex. The use of the ridge/swale complex for stock grazing seems to have inhibited regeneration of these tree species, and to have turned most of the area into a sparse herbland dominated by *Lomandra longifolia* and *Pteridium esculentum* as reported elsewhere (Brown & Bayley-Stark 1979, Brown 1980, Dickinson & Kirkpatrick 1986). Cessation of stock grazing was followed by fuel accumulation and a fire which may have led to a further retreat of the eucalypts. Fire-stimulated germination of seeds of *Acacia sophorae* over most of the complex thus gave rise to its present dominance. However, *A. sophorae* is a short-lived species which relies on disturbance for its regeneration (Hazard & Parsons

1977). In the absence of another fire or mechanical disturbance through dune movement, it is likely to be replaced as a dominant on the ridge/swale complex by *Leucopogon parviflorus*, a bird dispersed species capable of continuous regeneration without disturbance (Hazard & Parsons 1977). If fires recur on the dune system, the nature of the resulting vegetation will be highly dependent on fire regime and the interaction of fire with grazing (cf. Brown 1980). In the early part of the nineteenth century, many of the coastal dune systems that are now covered by scrub or herbland were covered by scattered trees and tall shrubs over native tussock grass (Plomley 1966, Stockton 1982). Where tree species survive at Bakers Beach, such vegetation could be induced by low intensity burning at a frequency sufficient to prevent successful establishment of species such as *Acacia sophorae*, which rely on regeneration from seed rather than vegetative recovery. Occasional severe fires, however, will encourage the latter species and prevent growth of tree seedlings.

The large herbivore density on the dunes is such that *Spinifex hirsutus* open-grassland on the fore-dune is cropped to lawn height by wombats, and scat densities are high throughout the ridge/swale complex. The potential influence of these herbivores on tree and shrub seedling regeneration is hard to predict, although it is known that the effects of herbivores can be dramatically increased by other sources of disturbance such as fire (Leigh & Holgate 1979, Dickinson & Kirkpatrick 1986). Heavy grazing pressure may favour herbs and grasses rather than shrubs (Dickinson & Kirkpatrick 1986). There is little likelihood that even severe fire will dramatically reduce herbivore numbers, as the main focus of grazing activity is on fire-resistant former paddocks to the rear of the dunes.

Context and Conservation Importance

Although most of the Bakers Beach sand dune vegetation is in a less pristine state than that of Rheban Spit (Bowden & Kirkpatrick 1974) or the Maria Island isthmus (Brown & Bayley-Stark 1979), enough elements of the original vegetation remain to show that, with a few minor exceptions, zonation is similar. Bakers Beach, unlike the other two systems, has not been invaded by marram grass (*Ammophila arenaria*), and the native sand-binder is *Spinifex hirsutus* rather than *Festuca littoralis*. The swamps in southeastern Tasmania are dominated by *Melaleuca squarrosa* rather than *M. ericifolia*. However, the three areas lack the Victorian element of coastal sand dune species present in the far northeast and northwest of mainland Tasmania (Kirkpatrick, in press).

The reservation status of the vegetation complex found on coastal sand dune systems is relatively poor, because of the demand for such areas for agricultural and recreational (shack) development. Thus, the Bakers Beach area, despite its present degraded state, is an important area for long-term conservation of sand dune vegetation and its associated fauna. It is a valuable area for location of permanent monitoring plots and exclosure plots, to record vegetation change and assess the impact of fauna in an apparently dynamic system.

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REFERENCES

Barson, M.M. & Calder, D.M., 1981: The vegetation of the Victorian coast. *Proc. R. Soc. Vict.* 92: 4–65.

Bowden, A.R. & Kirkpatrick, J.B., 1974: The vegetation of Rheban Spit, Tasmania. *Pap. Proc. R. Soc. Tasm.* 108: 199–210.

Brown, M.J., 1980: The vegetation of the Mt Cameron West Aboriginal Site. *Pap. Proc. R. Soc. Tasm.* 114: 21–34.

Brown, M.J. & Bayley-Stark, J.H., 1979: Vegetation of Maria Island. *Wildl. Div. Tech. Rep.* 79/1. Tasm. NPWS: 99 pp.

Bureau of Meteorology, 1979: *CLIMATIC SURVEY TASMANIA, REGION 3 NORTHERN.* Department of Science and the Environment, Canberra: 64 pp.

Canfield, R., 1941: Application of the line interception method in sampling range vegetation. *J. Forest.* 39: 388–394.

Curtis, W.M., 1963: *THE STUDENT'S FLORA OF TASMANIA, PART II.* Government Printer, Hobart.

Curtis, W.M., 1967: *THE STUDENT'S FLORA OF TASMANIA, PART III.* Government Printer, Hobart.

Curtis, W.M. & Morris, D.I., 1975: *THE STUDENT'S FLORA OF TASMANIA, PART I.* 2nd edition, Government Printer, Hobart.

Davies, J.L., 1978: Beach sand and wave energy in Tasmania. *In* Davies, J.L. & Williams, M.A.J. (Eds): *LANDFORM EVOLUTION IN AUSTRALASIA.* Oxford University Press, Canberra: 158–167.

Davis, C., 1940: Preliminary survey of the vegetation near New Harbour, Tasmania. *Pap. Proc. R. Soc. Tasm.* 1940: 1–90.

Dickinson, K.J.M. & Kirkpatrick, J.B., 1986: The impact of grazing pressure in clearfelled, burned and undisturbed eucalypt forest. *Vegetatio* 66: 133–136.

Hazard, J. & Parsons, R.F., 1977: Size-class analysis of coastal scrub and woodland, Western Port, South Australia. *Aust. J. Ecol.* 2: 187–198.

Hill, M.O., 1979: *TWINSPAN — A FORTRAN PROGRAM FOR ARRANGING MULTI-VARIATE DATA IN AN ORDERED TWO-WAY TABLE BY CLASSIFICATION OF THE INDIVIDUALS AND ATTRIBUTES*. Section of Ecology and Systematics, Cornell University, Ithaca.

Hill, M.O. & Gauch, H.G., 1980: Detrended correspondence analysis: an improved ordination technique. *Vegetatio* 42: 47–58.

Kirkpatrick, J.B., 1973: The vegetation of Sloping Island, Tasmania. *Vict. Nat.* 90: 313–321.

Kirkpatrick, J.B., 1975: Phytosociological analysis of the vegetation of Lagoon Beach, Tasmania. *Pap. Proc. R. Soc. Tasm.* 109: 53–63.

Kirkpatrick, J.B., in press: Dry coastal vegetation in southeastern Australia. *In* Mauri, E. van der (Ed.): *DRY COASTAL ECOSYSTEMS*. Elsevier, Amsterdam.

Kirkpatrick, J.B. & Harwood, C.E., 1983: Plant communities of Tasmanian wetlands. *Aust. J. Bot.* 31: 437–451.

Ladd, P.G., Ladiges, P.Y. & Calder, D.M., 1976: *IDENTIFICATION OF THE LAND-BASED VEGETATION SURROUNDING THE GIPPSLAND LAKES AND LAKE TYERS*. Ministry for Conservation, Victoria.

Leigh, J.H. & Holgate, M.D., 1979: The responses of the understorey of forests and woodlands of the Southern Tablelands to grazing and burning. *Aust. J. Ecol.* 4(1): 25–45.

National Parks & Wildlife Service, 1979: The impact of proposed pine plantations on wildlife in the West Tamar region, Tasmania. Unpubl. Rep. Tasm. NPWS.

Plomley, N.J.B., 1966: *FRIENDLY MISSION. THE TASMANIAN JOURNALS AND PAPERS OF GEORGE AUGUSTUS ROBINSON 1829–1834*. Tasmanian Historical Research Association, Hobart.

Ranwell, D.S., 1972: *ECOLOGY OF SALT MARSHES AND SAND DUNES*. Chapman and Hall, London.

Specht, R.L., 1970: Vegetation. *In* Leeper, G.W. (Ed.): *THE AUSTRALIAN ENVIRONMENT*, 4th edition. CSIRO and Melbourne University Press, Melbourne: 44–67.

Specht, R.L., 1972: *THE VEGETATION OF SOUTH AUSTRALIA*. 2nd edition, Government Printer, Adelaide.

Stephens, C.G. & Cane, R.F., 1939: The soils and general ecology of the north-east coastal region of Tasmania. *Pap. Proc. R. Soc. Tasm.* 1938: 201–208.

Stockton, J., 1982: Fires by the seaside: historic vegetation changes in northwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 116: 53–66.

Turner, J.S., Carr, S.G.M. & Bird, E.C.F., 1962: The dune succession at Corner Inlet, Victoria. *Proc. R. Soc. Vict.* 75: 17–33.

Willis, J.H., 1970: *A HANDBOOK TO PLANTS IN VICTORIA, VOLUME I*. 2nd edition, Melbourne University Press, Melbourne.

(accepted 14 April 1989)

REDESCRIPTION AND ECOLOGY OF THE ENDEMIC TASMANIAN SCINCID LIZARDS *LEIOLOPISMA MICROLEPIDOTUM* AND *L. PRETIOSUM*

by M. N. Hutchinson, P. Robertson and P. A. Rawlinson

(with four tables, three text-figures and two plates)

HUTCHINSON, M.N., ROBERTSON, P. & RAWLINSON, P.A., 1989 (31:x): Redescription and ecology of the endemic Tasmanian scincid lizards *Leiolopisma microlepidotum* and *L. pretiosum*. *Pap. Proc. R. Soc. Tasm.* 123: 257–274. ISSN 0080–4703. School of Biological Sciences, La Trobe University, Bundoora, Victoria 3083 (MNH); Arthur Rylah Institute for Environmental Research, PO Box 137, Heidelberg, Victoria 3084 (PR); and Department of Zoology, La Trobe University, Bundoora, Victoria 3083 (PAR) Australia.

Two species of scincid lizard, both hitherto identified as *Leiolopisma pretiosum*, occur syntopically on Mt Wellington, near Hobart, Tasmania. One of these is conspecific with the holotype of *Mocoa pretiosa* O'Shaughnessy, 1874, while the other is conspecific with the holotype of *Mocoa microlepidota* O'Shaughnessy, 1874, which has been regarded as a synonym of *L. pretiosum* since 1887. The two species are redescribed as members of an endemic Tasmanian subgroup within the Australian radiation of the genus *Leiolopisma* (*sensu* Greer 1982). *Leiolopisma microlepidotum* is confined to disjunct alpine populations in the south and west of Tasmania. It differs from *L. pretiosum* in colour pattern, larger size and more robust, less depressed head and body. Aspects of the biology and ecology of these and other Tasmanian endemic *Leiolopisma* species are also discussed.

Key Words: lizards, Scincidae, *Leiolopisma*, taxonomy, ecology, distribution.

INTRODUCTION

In 1874, O'Shaughnessy published descriptions of several new lizard species based on specimens received by the British Museum (Natural History) (BMNH). Amongst these were two specimens from Tasmania, which became the types of new species of the scincid genus *Mocoa* Gray, 1845; *M. pretiosa* and *M. microlepidota*. Boulenger (1887) transferred all *Mocoa* species to his section *Liolepisma* of the genus *Lygosoma*. Based on the holotypes, Boulenger relegated *Lygosoma microlepidotum* to the synonymy of *L. pretiosum*, and provided illustrations of the specimens under this new combination (pl.1). Since this time, the synonymy of *L. microlepidotum* with *L. pretiosum* has remained unchallenged (e.g. Cogger *et al.* 1983), while the generic placement of *pretiosa* has varied (Smith 1937, Mittleman 1952, Greer & Parker 1968), although it has remained closely associated with other Australian species placed in the genus *Leiolopisma* Duméril & Bibron, 1839 (Rawlinson 1974a,b, 1975, Greer 1974, 1979, 1982, Cogger *et al.* 1983). Greer (1979) placed *Leiolopisma* in the *Eugongylus* group (*Eugongylus* subgroup) of the subfamily Lygosominae (Greer 1970).

Field work in Tasmania in the late 1960's (PAR) and mid 1970's (MH) revealed the presence of distinctive high altitude populations of *Leiolopisma pretiosum*. More recently Greer (1982) has noted the morphological peculiarities (larger size, smaller scales) of *L. pretiosum* from the summit of Mt Wellington compared with lower altitude populations from other parts of Tasmania. In January 1980, MH and PR carried out field work in Tasmania as part of studies on the relationships and ecology of Australian skinks. During this time, collections were made of both the larger, small-scaled form of *L. pretiosum* on the summit of Mt Wellington, and the smaller, large-scaled form from lower down the mountain. At one site both forms were found together, literally on adjacent rocks. There was no sign that the two forms were intergrading with each other or with other *Leiolopisma* species (*L. metallicum* and *L. ocellatum*) which were also present. This indicated that two biological species were included under the name *L. pretiosum*.

During 1973, PAR made a detailed examination of O'Shaughnessy's types in the BMNH collection. Based on this, it is now clear that the holotype of *M. pretiosa* is a specimen of the smaller, "lowland" form, while the holotype of *M. microlepidota* is a specimen of the larger "highland" form. Thus Boulenger was incorrect in synonymising *Lygosoma pretiosum* and *L. microlepidotum*, and

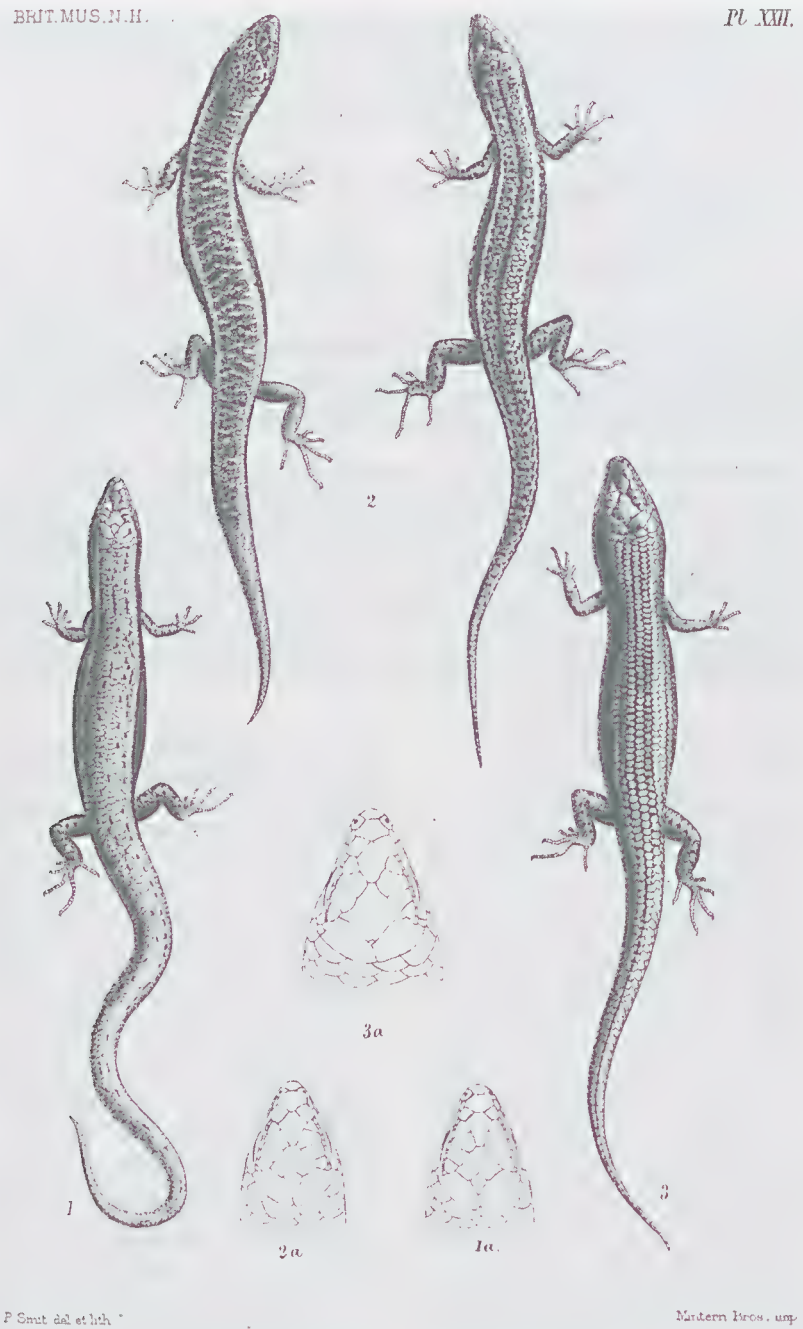

PLATE 1

Plate XXII from Boulenger (1887), which illustrated O'Shaughnessy's types of Mocoa microlepidota *(fig. 2, left) and* M. pretiosa *(fig. 2, right). The two were synonymised by Boulenger under the combination* Lygosoma pretiosum. *Reproduced by permission of the British Museum (Natural History).*

PLATE 2

Four species of Leiolopsima endemic to mainland Tasmania. (A) L. greeni, *ad. male, Mt Barrow; (B)* L. microlepidotum, *ad. male, Mt Wellington; (C)* L. ocellatum, *ad. male, Cataract Gorge, Launceston; (D)* L. pretiosum, *ad. male, Cataract Gorge, Launceston.*

the species are redescribed based on the types and on specimens in Australian museums and in the collection of Tasmanian material currently under study by PR.

Both species have distinctive insular populations which have generated an unusual amount of intraspecific variation. In the case of *Leiolopisma pretiosum*, which is continuously distributed on the Tasmanian mainland, the insular populations are literally on continental islands off the southwest and northwest coasts of Tasmania. In the case of *L. microlepidotum*, the "islands" are disjunct areas of alpine habitat, generally above 1000 m elevation. Ecological notes are provided for both species, and comparative reproductive data are provided for these and two other mainland Tasmanian endemic *Leiolopisma* species, *L. greeni* and *L. ocellatum*.

Recently, Hutchinson *et al.* (1988) described a new species, *L. orocryptum*, from southwest Tasmania, in the course of which comparisons were made with both *L. pretiosum* and *L. microlepidotum*. The present paper, which was intended to have appeared first, provides the justification for treating the latter two as distinct.

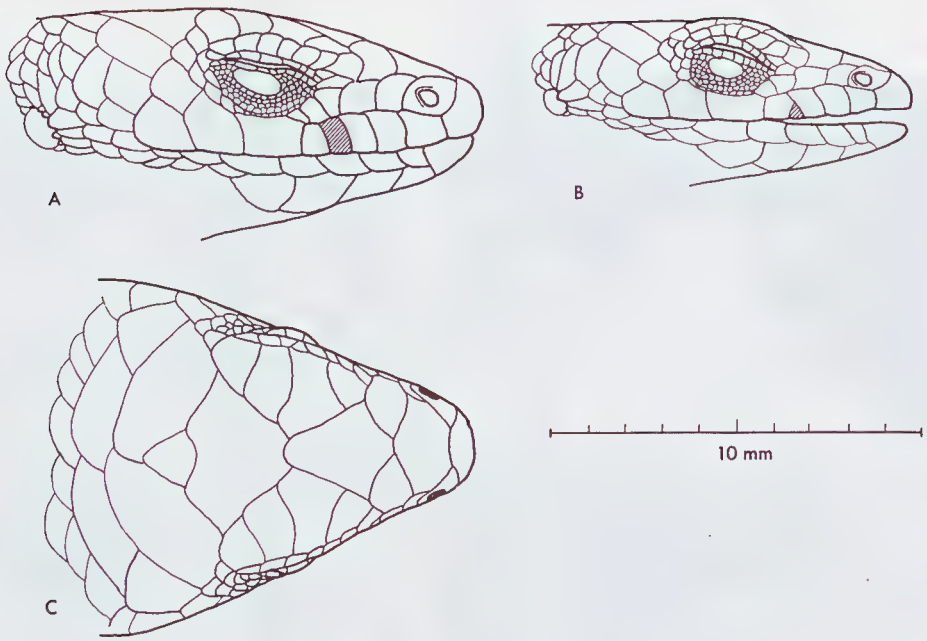

FIG. 1 — Lateral views of head scalation. (A) Leiolopisma microlepidotum *(female, Mt Wellington pinnacle, PR TF69, SVL 62 mm); (B)* L. pretiosum *(female, Mt Wellington "chalet", PR TF10, SVL 50 mm); in both species, the cross-hatched supralabial may be complete, giving a total of 8 supralabials, incomplete, as in (B) or absent, giving a total of 7 supralabials. (C) dorsal view of head scalation in* L. microlepidotum *(same specimen);* L. pretiosum *similar.*

METHODS

Definitions of head shields and measurement positions are as described by Greer (1982). Measurements were made to the nearest millimetre using a ruler and to the nearest 0.1 mm using a calibrated microscope eyepiece or vernier calipers, from both preserved specimens (in alcohol or formalin) or from deep frozen specimens (after thawing). A list of specimens examined is given in the appendix. Institutional abbreviations follow Leviton *et al.* (1985), apart from some preserved whole specimens and osteological specimens in the collections of PR and MH respectively.

Skulls were prepared by manual dissection of the soft tissues away from the bone, using fine forceps. Drawings of skulls and head shields were made using a binocular microscope equipped with a drawing tube.

Colour notes were taken from alcohol-preserved specimens and from frozen specimens (in which ephemeral alcohol-soluble pigments were preserved), as well as from colour photographic transparencies (Kodachrome 64).

Statistical procedures were as outlined by Parker (1973).

DESCRIPTIONS OF THE TAXA

Leiolopisma Duméril & Bibron, 1839

As redefined by Greer (1974), this is a grade group of small to moderate lygosomine skinks showing all of the features of the *Eugongylus* subgroup of the *Eugongylus* group (Greer 1979; = Group II species of Greer 1974). Within the *Eugongylus* group, the Australian species of *Leiolopisma* are diagnosed by: supranasals and/or postnasals present or absent; prefrontal shields well developed,

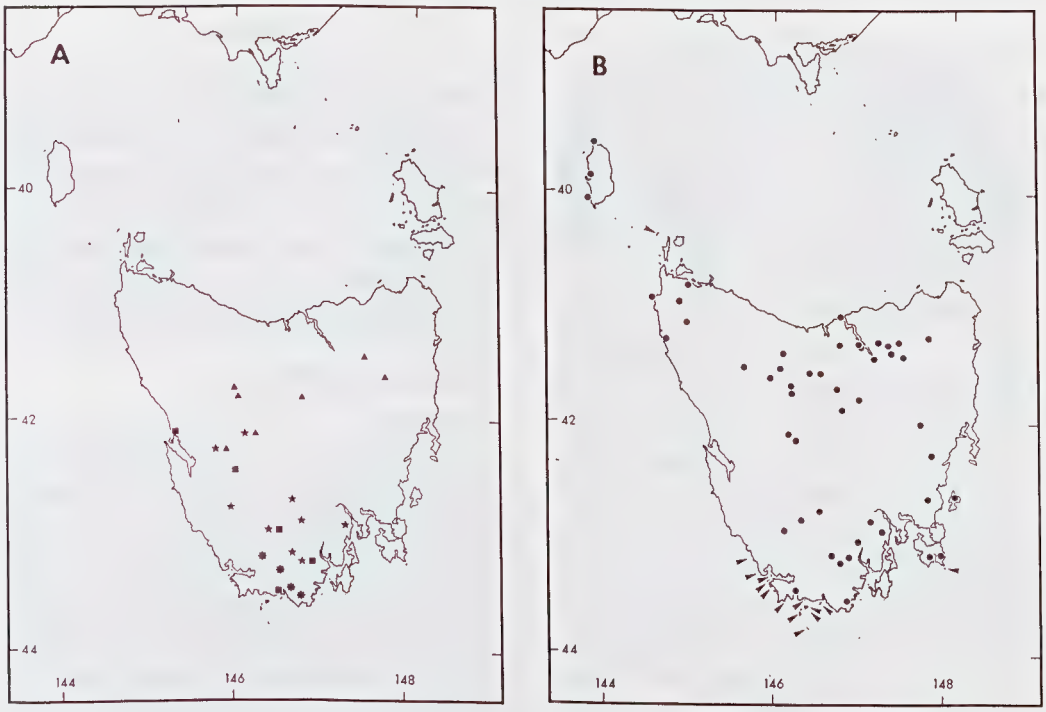

FIG. 2 — (A) distributions of the three species of alpine skinks, Leiolopisma greeni *(triangles),* L. microlepidotum *(stars) and* L. orocryptum *(squares), endemic to Tasmania; asterisks indicate populations apparently composed primarily of hybrids between* L. microlepidotum *and* L. orocryptum*; (B) distribution of* L. pretiosum *in Tasmania and its offshore islands (arrowed).*

separated or in contact; frontoparietals paired or fused, the interparietal always distinct; lower eyelid moveable with a moderate to large transparent palpebral disc; limbs well developed, pentadactyl; reproduction viviparous or oviparous.

Australian species: *baudini* Greer, 1982; *coventryi* Rawlinson, 1975; *duperreyi* (Gray, 1838); *entrecasteauxii* (Duméril & Bibron, 1839); *greeni* Rawlinson, 1975; *jigurru* Covacevich, 1984; *metallicum* (O'Shaughnessy, 1874); *microlepidotum* (O'Shaughnessy, 1874); *ocellatum* (Gray, 1845); *orocryptum* Hutchinson, Schwaner & Medlock, 1988; *palfreymani* (Rawlinson, 1974); *platynotum* (Peters, 1881); *pretiosum* (O'Shaughnessy, 1874); *rawlinsoni* Hutchinson & Donnellan, 1988; *spenceri* (Lucas & Frost, 1894); *trilineatum* (Gray, 1838); *zia* Ingram & Ehmann, 1981.

Leiolopisma microlepidotum (O'Shaughnessy, 1874) (Pls 1, 2A; figs 1A,C, 2A, 3A–C)

Mocoa microlepidota O'Shaughnessy (1874: 299).

Lygosoma (*Liolepisma*) *pretiosum* (part) Boulenger (1887: 282, pl. XXII, fig. 2 (left)).

Lygosoma (*Leiolopisma*) *pretiosum* (part) Smith (1937: 225); Worrell (1963: 47).

Lamphropholis microlepidota Mittleman (1952: 27).

Leiolopisma pretiosum (part) Greer (1974: 17); Rawlinson (1974a: 319; 1975: 10); Greer (1979: 350; 1982: 566); Cogger *et al.* (1983: 170).

Diagnosis

Leiolopisma microlepidotum is distinguished from all other Australian *Leiolopisma* species by the following combination of character states: frontoparietal single; supranasals and postnasals

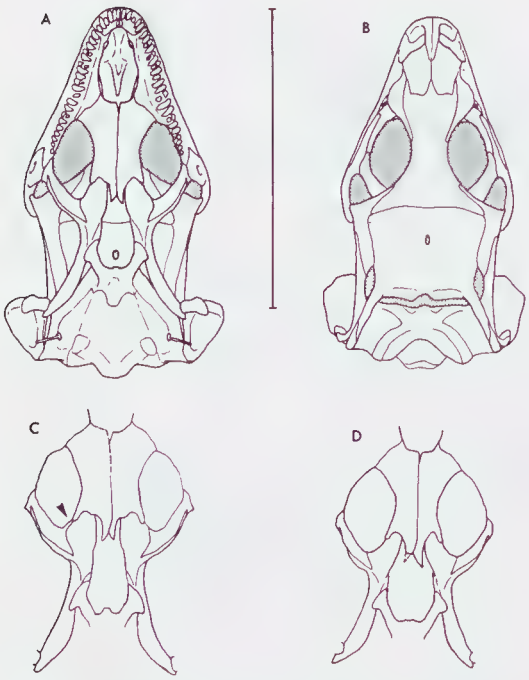

FIG. 3 — (A) palatal view of skull of adult male Leiolopisma microlepidotum *(Mt Wellington pinnacle, MH 86/17, SVL 54 mm); (B) dorsal view of skull of adult female* L. microlepidotum *(Mt Wellington pinnacle, MH 86/19, SVL 53 mm); (C) palate of mature male* L. microlepidotum *(Mt Wellington pinnacle, MH 86/2, SVL 60 mm) showing asymmetric development of an ectopterygoid process (arrowed); (D) palate of large male* L. pretiosum *(Flat Top Island, QVML 1985-3-72, SVL 58 mm).*

absent; midbody scales in 32–44 rows (modes geographically variable), dorsals smooth to weakly striate; colour pattern without well developed longitudinal stripes.

Distinguished from *L. greeni* by black upper lateral zone and tan dorsal ground colour, and fewer midbody scale rows (<38) in sympatric populations. Distinguished from *L. pretiosum* by absence of black vertebral and white midlateral stripes, larger size and less depressed head and body. Distinguished from *L. orocryptum* by absence of black vertebral and white midlateral stripes, and higher midbody scale counts (32 or more versus 32 or fewer).

Holotype

BMNH 1946.8.16.17 (old number 1867.10.1.5). Sex not determined. Van Diemens Land (= Tasmania). Collector/donor: G. Krefft. No other data. State of preservation good. The precise type locality is not specified in the BMNH records or the original description. The features of the holotype, especially the chequered colour pattern and 38 midbody scale rows, indicate that the holotype was probably collected from the Mt Wellington pinnacle, 1270 m elevation (42°56'S, 147°15'E).

Description of Holotype

Scalation

Midbody scales in 38 rows. Dorsals with three very weak striations; laterals with two weak striations. Paravertebrals not counted. Ventrals smooth, 83 between postmental and preanal (exclusive). Preanals ten, the median four slightly enlarged. Subdigital lamellae smooth, undivided, 21 under fourth toe. Supranasals and postnasals absent. Rostral and frontonasal in moderate contact. Prefrontals separated; frontal contacts frontonasal. Four supraoculars, second largest; first and second contact frontal. Frontoparietals fused. Interparietal distinct. Parietals large, in contact behind the interparietal. Each parietal bordered posterolaterally by the upper secondary temporal and enlarged nuchal. Supraciliaries seven. Upper ciliaries seven (fourth, fifth and sixth enlarged). Lower ciliaries eleven. Lower eyelid moveable, with a transparent palpebral disc. Supralabials seven, fifth subocular. Infralabials six. Ear opening obvious; no enlarged ear lobules.

Dimensions

Snout-vent length (SVL) 58 mm. Length of tail (broken) 45 mm. Length of forelimb 15 mm (26% of SVL). Length of hind limb 21 mm (36% of SVL). Length of eye 2.9 mm. Length of palpebral disc 1 mm (34% of eye length). Diameter of ear opening 0.9 mm.

Colour

Very dark brown dorsally, no dark vertebral stripe. Every third or fourth scale lighter olive brown, giving chequerboard-like pattern of pale patches. Light olive-brown dorsolateral zone runs unbroken from above eye to tail. Upper lateral zone black with two irregular rows of widely spaced small olive dots. No pale midlateral stripe, upper lateral zone merging into grey, dark-speckled, lower lateral zone. Venter unmarked pale grey.

Distribution

Leiolopisma microlepidotum is disjunctly distributed in mountainous areas in western and southern Tasmania (fig. 2A). It is known to occur as far north as Mt Rufus, and extends south at least to Mt Hartz. Most specimens have been taken from high altitude rocky herbfields, rock screes and lake margins, usually above 1000 m elevation. Far southern populations are problematic as intergradation with *L. orocryptum* is known to occur at some localities (Hutchinson & Schwaner, in prep.).

Variation

Scalation

Midbody scales in 32–44 rows, with marked geographic variation in modal counts (see below), dorsals weakly striate to smooth. Paravertebrals 61–81, again variable geographically; same size as adjacent dorsals. Subdigital lamellae on fourth toe 20–24 (mean 21.9, n=20). Postnasal and supranasal scales fused to nasal, but usually with a crescentic postnarial groove marking anterior margin of the fused postnasal. Anterior loreal single. Prefrontals usually separated (freq. 0.96). Supraciliaries usually 7 (0.85), occasionally 6, rarely 8. Supralabials seven or eight, depending on complete presence of additional supralabial between the third and fourth (see fig. 1). Asymmetry of supralabial and supraciliary counts is common. Presuboculars one or two. Temporals 1 + 2. Upper secondary temporal in contact dorsally with parietal and posteriorly with single enlarged nuchal. Postmental contacts first and second infralabials.

Dimensions

SVL of adult males 50–69 mm, adult females 51–68 mm. Hind limb 35.5–42.6 %SVL. Forelimb 25.8–32.0 %SVL. Original tail 131–147 %SVL (mean 141%, n=10). Head width sexually dimorphic in adults; range 14.1–16.3 (mean 15.0) %SVL in males, 12.4–15.6 (mean 13.6) %SVL in females.

Colour

In preservative, dorsal surfaces of head, body and tail light to dark-brown, olive or greyish. Scales of back edged and flecked with black, with dark markings more or less regularly arranged to form a crudely chequered pattern. Dorsolateral scale row (row 4) usually weakly flecked or unmarked, producing a light dorsolateral stripe. Dark markings may coalesce on the mid-dorsal line to produce a weak, ragged vertebral stripe, or may be so extensive that the dorsal pattern is better described as blackish with scattered lighter flecks (as in the holotype). Broad dark-brown to black upper lateral zone covers scale rows 5 to 8 or 9, often with small pale specks, and breaks up ventrally into a greyish, black-flecked lower lateral zone. Belly immaculate medium to light grey.

Colour in life as above, but most specimens with a greenish wash or iridescence, most obvious on the belly. Never any reddish ventral colouring.

Cranial osteology (figs 3A–C)

Postorbital bones absent and upper temporal fenestrae persistent. Prefrontals with anteriorly extending processes which reach almost to narial border, separating the maxillae and nasals. Palate typical of *Eugongylus* subgroup with palatines in contact and bearing posteromedial projections, and with pterygoids smoothly diverging along their inner margins. Pterygoid teeth absent. Vomers fused and bear a posteriorly directed triangular ridge which does not penetrate between palatines. Development of ectopterygoids variable; palatal process may be present (fig. 3C), almost excluding pterygoid from infraorbital vacuity. Premaxillary teeth eleven (five left, six right).

Leiolopisma microlepidotum (n=3) differs slightly but consistently from *L. pretiosum* (n=5) in having a higher, more robust skull, reflected by the heavier ectopterygoid bone. In two out of three skulls examined, the ectopterygoid has an anteromedial projection (the ectopterygoid process, Greer & Parker 1968) directed towards but not usually contacting the palatine; this process was absent in all *L. pretiosum*. Compared to *L. pretiosum*, *L. microlepidotum* has pterygoids which are relatively longer and with the quadrate rami disposed almost parallel to one another, rather than markedly diverging. The palatal rami of the pterygoids are also slightly expanded in *L. microlepidotum* but not in *L. pretiosum*. The larger size attained by *L. microlepidotum* is reflected in its dentary tooth counts, in which young adults have similar sized dentaries but fewer, larger teeth when compared with large adult *L. pretiosum*. Sexually mature *L. microlepidotum* have 23–27 homodont, peg-shaped teeth with obtusely pointed, slightly recurved crowns; in *L. pretiosum* the range is 26–28.

TABLE 1

Interpopulation Variation in *Leiolopisma microlepidotum*

Population	Midbody scale rows Range (mean)	Paravertebral scales Range (mean)	Adult SVL Range (n) (mm)	n
Mt Wellington	36–44 (39.3)	70–81 (76.9)	51–66 (47)	57
Mt Field	36–38 (36.7)	68–78 (73.3)	58 (1)	10
Mt Rufus	34–36 (34.9)	66–73 (70.0)	50–58 (6)	7
Mt Eliza	32–37 (34.9)	64–81 (70.9)	50–69 (29)	35
Mt Sprent	34–35 (34.2)	67–75 (70.5)	54–60 (4)	6
Mt Hartz	32–36 (33.3)	64–79 (70.4)	56–68 (17)	22

Geographic Variation

There are three distinct populations within this species, reflecting its disjunct distribution. Some of the variation characterising these populations is summarised in table 1.

Mt Wellington animals have much the smallest body scales. This is the only population known to include specimens with 40 or more midbody scale rows, and 38 and 40 are the modal midbody scale row counts for this population. Paravertebral scale counts also average much higher in this population.

To the west is the isolated Mt Field plateau, where specimens have 36 or 38 midbody scale rows and relatively high paravertebral counts. These animals are intermediate meristically and geographically between Mt Wellington and the main south-central Tasmanian highland populations, represented in table 1 by the Mt Rufus, Mt Sprent and Mt Eliza specimens. In these populations there are usually 34 or 36 midbody scale rows and about 70 paravertebrals. At Mt Rufus, where *L. microlepidotum* is sympatric with *L. greeni*, the sample of *L. microlepidotum* has smaller body sizes than average, possibly representing a case of character displacement with respect to body size. The five adult male *L. microlepidotum* were between 50 and 56 mm SVL (mean 52), while the single adult female was 58 mm. Eight adult male *L. greeni* ranged from 55 to 69 mm SVL (mean 63) while 13 females were between 59 and 70 mm (mean 65).

Southern mountain ranges (Mt Hartz area, Mt La Perouse/Precipitous Bluff and the Eastern Arthurs) support populations of skinks morphologically like both *L. microlepidotum* and *L. orocryptum*. The difficulties experienced in assigning specimens to species based on external morphology prompted the use of allozyme electrophoresis, which has resulted in the discovery that specimens from the latter two areas are mostly genetic intergrades between the two species (Hutchinson & Schwaner, in prep.). On the Mt Hartz plateau, the two species have not been recorded intergrading, but nevertheless can show confusing overlap in morphology — so much so that all specimens were initially identified as *L. microlepidotum*, while it was acknowledged that they showed apparent overlap with *L. orocryptum* (Hutchinson *et al.* 1988). Electrophoretic sorting of a sample of specimens from around Mt Hartz showed that two species, separated by four fixed genetic differences, occurred syntopically. Most could be assigned to species using external morphology as follows:

Colour pattern including a continuous white midlateral stripe and a black vertebral stripe, and/or 32 or fewer midbody scale rows ..... *L. orocryptum*
Colour pattern without either a continuous white midlateral stripe or a black vertebral stripe, and/or 32 or more midbody scale rows .... *L. microlepidotum*

However, some specimens are intermediate in colour pattern, for instance combining a well-developed black vertebral stripe with an indistinct midlateral white stripe, and may have exactly 32 midbody scale rows, and so are not readily assignable to species. Pending more complete

electrophoretic surveys, identification of alpine populations in far southern Tasmania will be difficult.

Leiolopisma pretiosum (O'Shaughnessy, 1874)

Pls 1, 2D; figs 1B, 2B, 3D

Mocoa pretiosa O'Shaughnessy (1874: 298).
Lygosoma (*Liolepisma*) *pretiosum* (part) Boulenger (1887: 282, pl. XXII, fig. 2 (right)).
Lygosoma (*Leiolopisma*) *pretiosum* (part) Smith (1937: 225); Worrell (1963: 47).
Lampropholis pretiosa Mittleman (1952: 29).
Leiolopisma pretiosum (part) Greer (1974: 17); Rawlinson (1974a: 319; 1975: 10); Greer (1979: 350; 1982: 566); Cogger *et al.* (1983: 170).

Diagnosis

Leiolopisma pretiosum is distinguished from all other Australian *Leiolopisma* by the following combination of character states: frontoparietal single; supranasal and postnasal scales absent; midbody scales in 32–40 (usually 32–36) rows, the dorsals smooth or striate; body and head depressed, eyes bulging markedly above flattened frontal region; white midlateral stripe usually well developed; dorsal colour pattern usually includes black vertebral stripe and both darker and lighter flecks on a brown background.

Most similar in external appearance to *L. metallicum*, *L. microlepidotum* and *L. orocryptum*. *L. metallicum* has larger scales (24–28 rows at midbody), the dorsals are often markedly striate to weakly keeled, the paravertebrals are $1^1/_2$–2 times as wide as the adjacent dorsals and the limbs are shorter (hind limb usually less than 38% of SVL, versus more than 36% in *L. pretiosum*). *L. microlepidotum* is larger (breeding adults 50–69 mm SVL versus 44–57 mm for mainland Tasmanian *L. pretiosum*), the head and body are not markedly depressed and there is no white midlateral stripe. *L. orocryptum* has larger scales (28–32 rows at midbody) and never has pale dorsal speckling.

Holotype

BMNH 1946.8.16.54 (old number 1845.5.2.10). Sex not determined. Van Diemens Land (= Tasmania). Collector: Ronald Gunn. No other data. State of preservation moderate, skin slipping from some areas. The precise type locality is not specified in the BMNH accessions book, catalogue or original description. The features of the type specimen fall within the normal range of variation for mainland Tasmanian specimens, and the species is common in the vicinity of both Hobart and Launceston, so that it is not possible to suggest a more precise type locality.

Description of Holotype

Scalation

Midbody scales in 34 rows. Dorsal scales with four weak keels; lateral scales with three very weak keels. Paravertebrals not counted. Ventrals smooth, 80 between postmental and preanal (exclusive). Preanals ten, median four slightly enlarged. Palmar tubercles slightly enlarged. Subdigital lamellae smooth, undivided, 24 under fourth toe. Supranasals and postnasals absent. Rostral and frontonasal in moderate contact. Prefrontals separated; frontal contacts frontonasal. Four supraoculars, second largest; first and second contact frontal. Frontoparietals fused. Interparietal distinct. Parietals large, in contact behind interparietal. Each parietal bordered posterolaterally by upper secondary temporal and enlarged nuchal. Supraciliaries seven. Upper ciliaries seven (fourth, fifth and sixth enlarged). Lower ciliaries ten. Lower eyelid moveable, with a transparent palpebral disc. Supralabials seven, fifth subocular. Infralabials seven. Ear opening obvious; no ear lobules.

Dimensions

SVL 51 mm. Length of tail (regrown) 64 mm. Length of forelimb 15 mm (29% of SVL). Length of hind limb 20 mm (39% of SVL). Length of eye 2.3 mm. Length of palpebral disc 1 mm (43% of eye length). Diameter of ear opening 0.9 mm.

Colour

Brown dorsally with a black vertebral stripe and flecked with lighter and darker patches. Narrow dorsolateral light stripe runs from nostril, above eye, then continuously along anterior one-third of body, becoming fragmented posteriorly. Upper lateral zone black, bordered by a light midlateral stripe starting at ear and ending at hind limb. Lower lateral zone mottled grey and black. Venter unmarked grey, with dark mottling under chin.

Distribution

Leiolopisma pretiosum occurs in forests, woodlands and rocky areas throughout most of Tasmania (fig. 2B). It is also found on many of the adjacent small islands, including Maria, Tasman, Ile du Golfe, the Maatsuyker Group, and islets off the west coast. It occurs in the west of Bass Strait on King and Albatross Islands. Its occurrence in the east of Bass Strait is doubtful. Based on a single specimen (NMV D911) donated by Kershaw, Rawlinson (1967) recorded *L. pretiosum* from Flinders Island (Furneaux Group). However, there is some doubt about the accuracy of the data with many of Kershaw's specimens (A.J. Coventry, pers. comm.), and although the reptile fauna of Flinders Island has been comparatively well surveyed, no further *L. pretiosum* specimens have been collected. The species ranges from sea level up to about 1000 m elevation.

Variation in Mainland Populations

Ninety-three specimens from the Tasmanian mainland have been examined to assess variation within the main population of this species.

Scalation

Midbody scales in 32–38 rows (mode 34, mean 34.0), dorsals smooth to weakly keeled. Paravertebrals 58–69 (mean 62.6); only slightly broader than adjacent dorsals. Subdigital lamellae on fourth toe 20–25 (mean 22.6, n=20). Postnasal and supranasal scales fused to nasal, but usually with crescentic postnarial groove marking the inner margin of the fused postnasal. Anterior loreal single. Prefrontals usually separated (freq. 0.85). Supraciliaries usually 7, occasionally 6 or 8. Supralabials 7, rarely 6 or 8; variation due to fusion of third and fourth supralabials or division of the third; fifth (of seven) supralabial subocular. Asymmetry of supralabial and supraciliary counts is common. Usually one presubocular. Temporals 1 + 2. Upper secondary temporal in contact dorsally with the parietal and posteriorly with the single enlarged nuchal. Postmental contacts first and second infralabials.

Dimensions

SVL of adult males 44–56 mm (n=20), adult females 45–57 mm (n=20). Hind limb 37.0–42.2 %SVL. Forelimb 27.4–33.3 %SVL. Original tail 119–144 %SVL (mean 137%, n=9). Head width sexually dimorphic in adults; range 13.4–15.3 (mean 14.4) %SVL in males, 12.1–13.6 (mean 13.1) %SVL in females.

Colour

In preservative, dorsal surface of head, body and tail pale grey-brown to medium metallic brown. Black vertebral stripe always detectable, but occasionally only weakly developed, running from nuchals to proximal part of tail. Scales of back usually lightly to heavily flecked with darker and lighter flecks; pale flecks sometimes absent, and more rarely dorsum immaculate apart from vertebral stripe. Upper lateral zone dark brown to black, sometimes speckled with white or pale grey, extends from scale row 4 to scale row 7 or 8. This zone narrowly edged above by whitish dorsolateral line (sometimes absent) and below by white midlateral stripe from neck to groin. This stripe has an irregular blackish lower margin. Top of head and legs flecked blackish. Underside off-white to light grey, often with dark-edged throat and chin scales.

Colour in life as above, but underside of most adults with vague to moderately intense orange or pink flush, usually running from posterior third of belly to proximal quarter of tail.

Cranial osteology (fig. 3D)

Similar in most respects to *L. microlepidotum* (see above).

Variation in Insular Populations

Table 2 summarises interpopulation variation in several characteristics of this species.

Throughout mainland Tasmania this species shows relatively little variation in size, colour or scalation. A slight south to north cline is apparent, with northern animals being marginally larger and averaging slightly higher midbody scale counts — counts of 36 are more common in the north, and one northern specimen is the only mainland *L. pretiosum* recorded with 38 midbody scale rows. However, much more variation is seen in specimens from offshore islands, as shown in table 2. A recurring trend is for island animals to be larger and have smaller midbody scales (higher row counts) than is usual for mainland specimens, and on some islands these values range higher than any mainland population. In addition, instances of head shield variations which are rare in mainland populations become common or even usual in certain island populations. Thus over half of the Albatross Island specimens have a transverse suture

TABLE 2

Interpopulation Variation in *Leiolopisma pretiosum*

Island	Midbody scale rows Range (mean)	Paravertebral scales Range (mean)	Adult SVL Range (mm)	n
Tasmania				
Overall	32–38 (34.0)	58–69 (62.6)	44–57	93
South (Hartz Mt, Mt Wellington)	32–36 (33.9)	58–67 (61.7)	44–57	45
North (Tamar vly, Maggs Mt)	32–38 (34.3)	59–68 (64.2)	45–56	27
King Island	32–38 (34.5)	59–71 (62.8)	44–61	30
Albatross Island†	32–38 (35.8)*	63–80 (68.8)*	49–60	36
Swainson Island‡	33–34 (33.6)	60–67 (62.2)	53	5
Breaksea Islands§	32–36 (34.7)	61–67 (63.5)	51–55	9
De Witt Island	33–36 (35.1)**	61–67 (63.6)	47–56	12
Flat Top Island	36–38 (37.2)*	66–70 (67.8)*	52–58	6
Maatsuyker Island	32–36 (33.6)	60–70 (63.7)	44–55	29
Mewstone¶	34–40 (37.4)*	62–73 (67.3)*	52–70	30
Louisa Island#	34–37 (35.5)**	59–65 (61.3)	49–53	9
Ile du Golfe	32–36 (34.0)	58–66 (61.9)	47–56	44
Tasman Island	34–37 (35.5)**	64–74 (67.5)*	45–57	12

Notes:
† 53% of specimens have "interprefrontal" shield.
‡ Four specimens (80%) with prefrontals in contact.
§ Five specimens (56%) with prefrontals in contact.
¶ Some specimens in poor condition; midbody scale counts taken from 30 specimens, paravertebrals from 28.
# Two specimens (22%) with divided frontoparietals.
Asterisks indicate significant differences from mainland specimens (overall values) using Student's t-test:
* $p < 0.001$, ** $0.01 > p > 0.001$

across the anterior one-third of the frontal, forming an azygous "interprefrontal" shield. This peculiarity was seen in only one of 93 mainland specimens. Other island abnormalities included fusions or partial fusions involving the parietals, nuchals and prefrontals, divisions of the frontoparietals and partial separation of supranasal and postnasal scales.

The most distinctive island population is from the Mewstone, the southernmost and deepest water islet supporting *L. pretiosum*, and also one of the smallest. The islet is a rocky peak only 6.8 ha in area (White 1981), is almost unvegetated, and lies in 110 m of water (Rawlinson 1974a). Mewstone animals are by far the largest *L. pretiosum* (table 2) and have the smallest scales, the modal count being 38 and ranging as high as 40. Most also have the supranasals partially separated posteriorly. Although younger specimens, and some adults, have a colour pattern typical of mainland *L. pretiosum*, many larger individuals may be aberrant in colour pattern, with a heavy suffusion of black markings, and most live specimens have a greenish sheen. The venter is usually yellow-green with an orange wash on the posterior belly and proximal tail. The small sample from Flat Top Island, a small (2 ha) deep-water (91 m) islet 12.6 km to the northeast, resembles the Mewstone population in the modal midbody scale count of 38. It is interesting to note that in scalation, colouring and relatively large size, Mewstone animals approach *L. palfreymani*, a species confined to Pedra Branca Islet about 62 km ESE of the Mewstone. *L. palfreymani* has well developed supranasal and postnasal scales, 38 or 40 midbody scale rows, and reaches a still larger maximum size (92 mm SVL).

TABLE 3

Comparisons of Scalation and Adult Size in Sympatric and Adjacent Populations of *Leiolopisma microlepidotum* and *L. pretiosum*

Population	Midbody scale rows Range (mean)	Paravertebral scales Range (mean) (mm)	Adult SVL Range (mean)
A. Sympatry			
Mt Wellington "chalet"			
L. microlepidotum (n=5)	38–42 (40.6)	77–80 (77.8)	58–62 (59.6)
L. pretiosum (n=7)	32–36 (33.9)*	60–65 (62.6)*	48–53 (50.0)*
B. Parapatry			
Mt Wellington pinnacle			
L. microlepidotum (n=52)	36–44 (39.2)	70–81 (76.8)	51–66 (58.9)
Mt Wellington "geology sign"			
L. pretiosum (n=27)	32–36 (33.9)*	58–67 (61.7)*	44–57 (50.9)*
Mt Rufus summit			
L. microlepidotum (n=7)	34–36 (34.9)	66–73 (70.0)	50–58 (53.0)
Mt Rufus lower slopes			
L. pretiosum (n=7)	32–36 (34.3)	60–64 (62.1)*	47–52 (49.7)*
Hartz Mt National Park			
– L. Osborne/L. Perry/Ladies Tarn			
L. microlepidotum (n=9)	32–35 (33.4)	64–79 (70.1)	56–68 (61.1)
– Waratah lookout			
L. pretiosum (n=9)	33–36 (34.2)	59–64 (60.9)*	44–54 (47.6)*

* *L. pretiosum* significantly different (t-test, $p < 0.001$) from the corresponding data for *L. microlepidotum*.

SYMPATRY OF *L. MICROLEPIDOTUM* AND *L. PRETIOSUM*

On Mt Wellington, samples of five *L. microlepidotum* and seven *L. pretiosum* were collected during January 1980 at "The Chalet", a roadside rotunda, at an elevation of 1000 m, just below the treeline. This locality is 4 km from the pinnacle along the main Mt Wellington road. There is no evidence of intergradation in the characters which distinguish the species (size, midbody and paravertebral scalation, colour; table 3), nor is any overlap apparent with the two other species, *L. metallicum* and *L. ocellatum*, which occur at this locality.

Three other areas of close parapatry or possible sympatry are known, Mt Rufus, Mt Picton and the Hartz Mountain area. As shown in table 3, size and paravertebral scale counts separate both species at all localities, while at Mt Wellington midbody scale counts are also significantly different. At all localities, colour pattern is also an obvious guide to identification.

ECOLOGY AND REPRODUCTION

Both *L. microlepidotum* and *L. pretiosum* are agile, diurnally active, scansorial lizards adapted to living on fallen logs, trees or rock outcrops. *L. microlepidotum* appears to be restricted to the cold temperate zone (defined by Rawlinson 1974a), whereas *L. pretiosum* is also common in the cool temperate zone. Both species may occur in very high densities in suitable habitats, but nothing is known of their social organisation. *L. pretiosum* has been observed aggregating in communal refugia in log or rock crevices, and both species often bask in groups.

Leiolopisma microlepidotum occurs at high altitudes, where it appears to be restricted to more open habitats above the treeline. In these areas it is usually found in association with large rock outcrops, utilising exposed rock faces as basking sites and retreating into rock crevices or surrounding dense vegetation when disturbed. Presumably these sheltered sites are also used during periods of inactivity which, in alpine Tasmania, may be quite extensive. Foraging occurs on the open rock surfaces and in surrounding vegetation, and a variety of invertebrates is taken.

Leiolopisma pretiosum occurs in a range of habitats where there are trees or where rocks outcrop, usually at lower altitudes than *L. microlepidotum*. *L. pretiosum* uses the elevated surfaces of fallen logs, the trunks and lower limbs of trees, and, less frequently, rocks for basking sites. Where it coexists with the rock-dwelling *Leiolopisma ocellatum*, it may to some extent be displaced from rocky sites by that species. *L. pretiosum* forages widely from basking sites and also takes a wide variety of invertebrate prey.

On many of the small islands inhabited by *L. pretiosum*, and on low mountains of the far southwest mainland, trees are almost or totally absent (White 1981). In these habitats, *L. pretiosum* is a rock dweller (other saxicoline species appear to be absent), and crevices in rocks are used as retreats. Some of the smallest islets almost completely lack vegetation of any kind, but on at least one such islet, the Mewstone, a large population of *L. pretiosum* is apparently supported by the islet's colony of shy albatross (*Diomedea cauta*). Lizards have been observed feeding on fish remains in the colony, and even feeding inside the carcasses of dead albatross chicks (Rounsevell *et al.* 1985, N. Brothers, pers. comm. 1987). In this respect, *L. pretiosum* is similar to *L. palfreymani* (Pedra Branca islet, Tasmania) and *L. nigriplantare* (Chatham Islands, New Zealand), which also inhabit small sea-bird islands and live at least partly off the nesting colonies (McCann 1955, Rounsevell *et al.* 1985).

Both species are shuttling heliotherms, maintaining body temperatures (when active) within relatively narrow limits, often well above ambient, by alternating between basking and moving to shaded areas. Rawlinson (1974a) stated that for *L. pretiosum* the normal activity range is from a voluntary minimum of 21.5°C to a voluntary maximum of 37.2°C, with a mean of 29.1°C (n=8) when measured in the laboratory. Greer (1982) measured in the field the body temperatures of 30 individuals from the summit of Mt Wellington. He found that the active body temperature of this species ranged from 22.6°C to 31.8°C, with a mean of 27.3°C. Air temperature at that time ranged from 13.2°C to 19.9°C (mean 17.6°C), with the greatest difference between a lizard body temperature and adjacent air temperature being 18.6°C. The difference between the mean active body temperatures quoted for *Leiolopisma pretiosum* and *L. microlepidotum* may only reflect the differing experimental methods used in obtaining these data, but it is interesting to note that the species inhabiting the colder environment appears to be more "cold adapted", with a lower mean ("preferred") body temperature.

Weekes (1930) looked at reproduction and placentation in what she referred to as *L. pretiosum* collected from Mt Wellington. As both *L. pretiosum* and *L. microlepidotum* occur at this general locality, her material may have consisted of either or both species. It appears that reproductive details are very similar in these closely related species, so her findings on placental structure are probably applicable to both. Rawlinson (1974a) and Greer (1982) listed a number of reproductive details for *L. pretiosum*, and these may be variously attributed to *L. pretiosum* or *L. microlepidotum* as discussed below.

Both species are viviparous, sustaining the embryos within the oviducts via simple placentation and giving birth to live young. It appears probable that most of the nutrients necessary for development of the embryos are contained within the yolk deposited on the ova prior to ovulation, and that the allantoplacenta functions mainly for the exchange of water and respiratory gases (Weekes 1930). Adequate reserves, in the form of abdominal fat bodies, are thus needed for reproduction. They accumulate slowly from food consumed during periods of activity, and are used rapidly in the formation of yolk for the developing ova.

Like most other viviparous species of Australian *Leiolopisma*, *L. pretiosum* and *L. microlepidotum* have obligate sperm storage during the winter period of inactivity (Rawlinson 1974a). Maximum testis size, and presumably mating, occurs in late summer or autumn, directly after the birth of the young, and the sperm must be stored by the females until spring, when ovulation and fertilisation take place. The gestation period is variable, depending on local climate. For example, *L. pretiosum* from lowland northern Tasmania have been recorded giving birth in early January, while specimens from higher altitudes or more southerly latitudes, where time available for activity each year can be much less, may give birth as late as April. Similarly, *L. microlepidotum*, living in the cooler southern, high-altitude areas, would not usually give birth until autumn. In fact, Swain (1972) suggested that some females of some species of Tasmanian skinks may retain the embryos in the oviducts during the winter and give birth the following spring. Our observations lend some support to this contention: firstly, *L. microlepidotum* collected from Mt Wellington in January had embryos at a very early stage of development; secondly, apparently recently born individuals of *L. microlepidotum* were collected from Mt Hartz in early February, when some females were carrying early embryos; and thirdly, some *L. pretiosum* collected from the Mewstone in May were still carrying near-term embryos.

The litter size of the two species is similar (table 4), with a range of 1–4 for *L. microlepidotum* and 1–3 for *L. pretiosum*. The closely related *L. orocryptum*, *L. ocellatum* and *L. greeni* also have small litters (3–4, 1–4 and 2–3 respectively), a characteristic of the *L. spenceri* group (Greer 1982). There may be some difference between *L. pretiosum* and *L. microlepidotum* in the size of young at birth, neonates of the former measuring 22–24 mm SVL (mean 23.1, n=8), while the smallest juveniles of *L. microlepidotum* are 24–33 mm SVL. Neonate sizes are not available for *L. microlepidotum* as all pregnant females collected by the authors (on several occasions and from several localities) have aborted within a few days; size data are therefore from the smallest field-caught juveniles (n=6).

It is not known how long juveniles of either species take to reach reproductive size. No distinct yearly size classes are discernible in the available samples of pre-reproductive individuals, but these samples indicate that both species probably take at least two years to reach sexual maturity. The true time could be much longer and may be variable, depending on locality and possibly on climatic differences between years. Males of *L. pretiosum* from 44–56 mm SVL have been recorded with enlarged testes, and females with young measure 44–57 mm SVL (mainland Tasmanian populations). Size at maturity is greater in *L. microlepidotum*, males ranging 50–69 mm and females 51–68 mm.

The percentages of females which reproduce in any given season for the five Tasmanian endemic *Leiolopisma* for which data are available are shown in table 4. Greer (1982) has already noted that not all females in a sample of *L. greeni* collected by him were pregnant. Our data indicate that, while all females of the two species characteristically found at lower altitudes (*L. ocellatum* and *L. pretiosum*) breed each year, a proportion of females of the three montane species (*L. greeni*, *L. microlepidotum* and *L. orocryptum*) do not breed each year. The cool climate and short growing season in alpine habitats could reduce the yearly activity of these species such that females cannot gather enough resources for reproduction in one season, or there may be insufficient time for embryonic development to be completed in one season. Both of these factors may force females to reproduce only every second year.

Biennial reproduction has been recorded in other reptiles inhabiting similar environments (Fitch 1970) but is not known in other Australian lizards. The data in table 4 indicate that usually more than 50% of females in samples of the three alpine species are recorded as breeding. This could be due to sampling bias, in that gravid females are more "catchable" (Shine 1980) and hence disproportionately represented in samples; or that when conditions are more favourable, in some localities or in some years, females may reproduce more frequently.

RELATIONSHIPS

Greer (1982), following Rawlinson (1974b, 1975), partitioned the Australian species of *Leiolopisma* into two species groups. These represent adaptive complexes to an arboreal/scansorial (*spenceri* group) or a terrestrial/grass-dwelling (*baudini* group) niche. It is not clear whether the groups represent monophyletic units (Shea 1987).

Several subgroups of biologically and morphologically similar species can be identified within each of Greer's species groups. The largest such subgroup can be termed the Tasmanian species group, since all are restricted to Tasmania and its adjacent islands. This subgroup consists of

TABLE 4

Female Reproductive Data for Five Endemic Tasmanian Skinks*

Species, locality & date	Number of adult females	Number of females reprod. (%)	SVL of adult females Range mm (mean)	Litter size Range (mean)
L. greeni				
Pine Lake				
Dec 1975	16	8 (50)	54–72 (63.7)	2–3 (2.2)[G]
Jan 1987	10	6 (60)	58–67 (61.7)	2–3 (2.3)
Mt Barrow				
Jan 1980	11	9 (82)	54–59 (56.3)	2
Mt Rufus				
Jan 1987	13	7 (54)	59–70 (63.5)	2–3 (2.3)
L. microlepidotum				
Mt Wellington				
Dec 1975	9	9 (100)	51–63 (?)	2–4 (2.4)[G]
Jan 1980	39	25 (64)	52–66 (57.5)	1–4 (2.6)
Mt Eliza				
Jan 1987	15	9 (60)	55–65 (58.4)	2–3 (2.3)
Mt Hartz				
Jan 1987	7	5 (71)	58–68 (63.4)	2–4 (2.8)
L. ocellatum				
Hamilton				
Jan 1980	13	13(100)	58–68 (63.0)	1–4 (2.7)
Lake St Clair				
Jan 1987	8	8(100)	61–73 (67.4)	2–4 (3.1)
various				
Dec 1975	11	11(100)	58–71 (64.4)	2–4 (2.6)[G]
Jan 1980	11	11(100)	54–71 (64.1)	1–3 (2.0)
L. orocryptum				
Mt Eliza				
Jan 1987	9	6 (67)	52–62 (56.7)	3–4 (3.1)
L. pretiosum				
Wilmot				
Dec 1975	5	5(100)	44–50 (48.0)	2–3 (2.2)[G]
Mt Rufus				
Jan 1987	6	6(100)	47–52 (49.7)	1–3 (2.0)
Mt Wellington				
Jan 1980	16	16(100)	49–57 (52.1)	2–3 (2.5)
Ile du Golfe				
Jan 1987	19	19(100)	47–54 (50.5)	2–3 (2.4)

* Data include both pregnant females and those which have recently given birth.
G Data from Greer (1982).

L. greeni, *L. microlepidotum*, *L. ocellatum*, *L. orocryptum*, *L. palfreymani* and *L. pretiosum*. They share the following combination of derived character states: frontoparietal shield single; midbody scales small to very small (in 28–58 rows); viviparous, with consistently small litters (1–4; no litter size data for *L. palfreymani*); limbs relatively long (33–47% of SVL; Greer 1982, table 8). As noted by Hutchinson *et al.* (1988), these Tasmanian endemics are probably more closely related to *L. metallicum* than to *L. spenceri*.

Although *L. microlepidotum* and *L. pretiosum* have so long been regarded as conspecific, there is no evidence which would suggest any closer relationship between the two than membership of the Tasmanian subgroup. Several characters are derived within the subgroup, such as decrease in scale size, enlargement of pterygoid or ectopterygoid bones, degree of dorso-ventral flattening and loss of the primitive "brown dorsum-black sides" colour pattern, but each species shows a different mosaic of primitive and derived states. Morphological, ecological and nearly-complete biochemical data indicate that *L. microlepidotum* is most closely related to the two other alpine species, *L. orocryptum* and *L. greeni*, while *L. pretiosum* has no obvious sister species.

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REFERENCES

Boulenger, G.A., 1887: *CATALOGUE OF THE REPTILES IN THE BRITISH MUSEUM (N.H.) III.* Taylor & Francis, London.

Cogger, H.G., Cameron, E.E. & Cogger, H.M., 1983: *ZOOLOGICAL CATALOGUE OF AUSTRALIA. I. AMPHIBIA AND REPTILIA.* Australian Government Publishing Service, Canberra.

Fitch, H.S., 1970: Reproductive cycles in lizards and snakes. *Misc. Publ. Mus. Nat. Hist. Univ. Kansas* No.52: 1–247.

Greer, A.E., 1970: A subfamilial classification of scincid lizards. *Bull. Mus. Comp. Zool. Harvard* 139: 151–183.

Greer, A.E., 1974: The generic relationships of the scincid lizard genus *Leiolopisma* and its relatives. *Aust. J. Zool., Suppl. Ser.* No.31: 1–67.

Greer, A.E., 1979: A phylogenetic subdivision of Australian skinks. *Rec. Aust. Mus.* 32: 339–371.

Greer, A.E., 1982: A new species of *Leiolopisma* (Lacertilia: Scincidae) from Western Australia, with notes on the biology and relationships of other Australian genera. *Rec. Aust. Mus.* 34: 549–573.

Greer, A.E. & Parker, F., 1968: *Geomyersia glabra*, a new genus and species of scincid lizard from Bougainville, Solomon Islands, with comments on the relationships of some lygosomine genera. *Breviora* 302: 1–17.

Hutchinson, M.N., Schwaner, T.D. & Medlock, K., 1988: A new species of scincid lizard (Lygosominae: *Leiolopisma*) from the highlands of Tasmania. *Proc. R. Soc. Vict.* 100: 67–73.

Leviton, A.E., Gibbs, R.H., Heal, E. & Dawson, C.E., 1985: Standards in herpetology and ichthyology: part I. Standard symbolic codes for institutional resource collections in ichthyology and herpetology. *Copeia* 1985: 802–832.

McCann, C., 1955: The lizards of New Zealand. Gekkonidae and Scincidae. *Dominion Mus. Bull.* 17: 1–127.

Mittleman, M.B., 1952: A generic synopsis of the lizards of the subfamily Lygosominae. *Smithson. Misc. Collns* 117: 1–35.

O'Shaughnessy, A.W.E., 1874: Descriptions of new species of Scincidae in the collection of the British Museum. *Ann. Mag. Nat. Hist.* 13: 298–301.

Parker, R.E., 1973: *INTRODUCTORY STATISTICS FOR BIOLOGY*. Edward Arnold, London.

Rawlinson, P.A., 1967: The vertebrate fauna of the Bass Strait islands. 2. The Reptilia of Flinders and King Islands. *Proc. R. Soc. Vict.* 80: 211–224.

Rawlinson, P.A., 1974a: Biogeography and ecology of the reptiles of Tasmania and the Bass Strait area. *In* Keast, A. (Ed.): *BIOGEOGRAPHY AND ECOLOGY IN TASMANIA*. W. Junk, The Hague.

Rawlinson, P.A., 1974b: Revision of the endemic southeastern Australian lizard genus *Pseudemoia* (Scincidae: Lygosominae). *Mem. Nat. Mus. Vict.* 35: 87–96.

Rawlinson, P.A., 1975: Two new lizard species from the genus *Leiolopisma* (Scincidae: Lygosominae) in southeastern Australia and Tasmania. *Mem. Nat. Mus. Vict.* 36: 1–16.

Rounsevell, D., Brothers, N. & Holdsworth, N., 1985: The status and ecology of the Pedra Branca skink, *Pseudemoia palfreymani*. *In* Grigg, G., Shine, R. & Ehmann, H. (Eds): *BIOLOGY OF AUSTRALASIAN FROGS AND REPTILES*. Surrey Beatty & Sons, Sydney.

Shea, G.M., 1987: Oviparity in *Leiolopisma jigurru* and a brief review of reproductive mode in *Leiolopisma*. *Herp. Rev.* 18: 29–32.

Shine, R., 1980: "Costs" of reproduction in reptiles. *Oecologia* 46: 92–100.

Smith, M.A., 1937: A review of the genus *Lygosoma* (Scincidae: Reptilia) and its allies. *Rec. Ind. Mus.* 39: 213–234.

Swain, R., 1972: The fauna of south-western Tasmania. *Tasm. Yearbook* No.16: 56–64.

Weekes, H.C., 1930: On placentation in reptiles. II. *Proc. Linn. Soc. N.S.W.* 55: 550–576.

White, G., 1981: *ISLANDS OF SOUTH-WEST TASMANIA* (enlarged edition). G. White, Sydney.

Worrell, E., 1963: *REPTILES OF AUSTRALIA*. Angus & Robertson, Sydney.

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APPENDIX

Specimens Examined

Leiolopisma microlepidotum: TASMANIA. Mt Hartz pinnacle (TMH C692, C698, C700–06, C709–712); Ladies Tarn, 2 km N of Mt Hartz (TMH C717, C720–23); Lake Osborne, Hartz Mt National Park (PR TF18–19, TF21); Lake Perry, Hartz Mt National Park (PR TF14); Picton area (NMV D10955); Mt Wellington pinnacle (AMS R9466, R81926–57, NMV D38007, PR TF64–109); Mt Wellington, 4100 ft (AMS R15889–90); 3 km (road) below Mt Wellington pinnacle (PR TF44–48); "Chalet", 4 km (road) below Mt Wellington pinnacle (PR TF1–5); "Hobart" (NMV D2086); Snowy Mountains (= Snowy Range) (TMH C107); Lake Fenton, Mt Field National Park (NMV D37996–97, D38008–12); Wombat Moor, Lake Dobson, Mt Field National Park (NMV D37978–79); Mt Anne (NMV D57599–600); Mt Eliza (TMH C624–656, C683, C687–88); Mt Sprent (TMH C780, C785–88, C791); Mt Rufus (NMV D37976, TMH C542, C576–80); no other data (BMNH 1946.8.16.17).

Leiolopisma pretiosum: TASMANIA. New Harbour, islet 100 m S of Smoke Signal Hill (QVML 1985-3-60); Cox Bight (TMH C108); Cataramaran (= Catamaran) (AMS R10052); Picton area (NMV D1125, D12724); Waratah Lookout, Hartz Mt National Park (PR TF25–29, TF132–35); 8 miles W of Geeveston (NMV D38005); Port Arthur (NMV D37980); Thumb Point, Tasman Peninsula (QVML 1985-3-71); West coast, between Macquarie Harbour and Port Davey (QVML 1972-3-200); Serpentine Creek (Lake Pedder) QVML 1967-3-15); Boyd River (TMH C781); Florentine Valley, Maydena (NMV D37975); Russell River, 5 km N of Judbury (AMS R71642); foot of Mt Wellington (NMV D38015); "Geology sign", 4 km (road) below Mt Wellington pinnacle (PR TF49–63, TF110, TF114, TF118, TF122–129, TF131); "Chalet", 4 km (road) below Mt Wellington pinnacle (PR TF6–11, TF130); Mt Wellington (AMS R5485–87); Collins Cap (SAMA R2872); Mt Rufus (TMH C581–87); Lyell Highway, $^1/_2$ mile E of Clarence River bridge (AMS R39010); 8.7 km (road) S of Buckland (AMS R78610–12); Tooms Lake (QVML 1975-3-17); 12 miles E of Campbell Town (NMV D37977); Poatina (NMV D50046); 5 miles S of Golden Valley (NMV D38017–21); 24 km S of Deloraine (AMS R86325; PR TF138); 17.4 km N of Breona via Lake Highway (AMS R78591–608); Great Lake (QVML 1972-3-124); Upper Mersey valley (QVML 1983-3-22); Maggs Mt (QVML 1978-3-216, 219, 221–22, 226, 238–243); Rowallan Dam (QVML 1986-3-10); 10 km NW of Lake McKenzie (QVML 1986-3-13); $7^1/_2$ miles S of Waratah turnoff (NMV D37981–82); Cradle Mt airstrip (QVML 1980-1-27); 26.8 km (road) S of Wilmot P.O. (AMS R78613–23); Wilmot (TMH C690); Mole Creek (QVML 1967-3-23); Needles, via Deloraine (QVML 1977-3-18); Cataract Gorge, Launceston (PR TF30–37, TF137); Cascade Gorge (= Cataract Gorge) (AMS R111396, R111401–02); First Basin, Cataract Gorge (QVML 1972-3-61); "near Launceston" (QVML 1978-3-115); $2^1/_2$ miles (road) below Mt Barrow summit (NMV D38023–05); 1 mile N of Mt Barrow (NMV D38003, D38013–14); Thornton Ridge, west coast (QVML 1981-3-119-120); West Point (AMS R64711); Julius Depot, northwestern Tasmania

(QVML 1978-3-107, 1986-3-22); 16 miles E of Marrawah (NMV D38002); West Frankford (QVML 1978-3-184); Tatana (= Exeter) (QVML 1972-3-62); Exeter (QVML 1972-3-170, 1975-3-9); Legana (PR TF38–43); Mt Arthur, "south side, $^2/_3$ way up" (QVML 1963-3-11); Mt Arthur (QVML 1984-3-14); 5 km S of Lilydale (AMS R102902–03); Myrtle Bank (QVML 1973-3-5); Mt Barrow road turnoff (NMV D38022); Ringarooma (QVML 1963-3-2); Kelso, Green's Beach (NMV D39943); Green's Beach (QVML 1972-3-141); 6 miles NNW of Smithton (NMV D38004); no other data (BMNH 1946.8.16.54).

KING ISLAND. Wickham (QVML 1973-3-13); Wickham Beach (QVML 1972-3-175); 1 mile E of Cape Wickham (NMV D37961–74); Loorana (QVML 1970-3-2, 1971-3-3); Porky Beach (QVML 1969-3-5; 1972-3-195); Cataraqui Point (QVML 1972-3-8).

ALBATROSS ISLAND. (NMV D37940–55; QVML 1973-3-3).

GREEN ISLAND. (QVML 1985-3-65).

TRUMPETER ISLAND. Main Island (QVML 1985-3-63).

EAST PYRAMIDS. (QVML 1985-3-52); West most (QVML 1985-3-55); East most (QVML 1985-3-51); Little Pyramid (QVML 1985-3-51).

MAVOURNEEN ROCKS. (QVML 1985-3-59).

BREAKSEA ISLAND. Main Island (QVML 1985-3-56); South Island (QVML 1985-3-58).

BIG CAROLINE ROCK. (QVML 1985-3-64).

SWAINSON ISLAND. (QVML 1985-3-55).

SUGARLOAF ROCK. (QVML 1985-3-54).

KETCHUM ISLAND. Unnamed islet 0.4 km E of Ketchum Island (QVML 1985-3-57).

LOUISA ISLAND. (AMS R80737–38; NMV D48809–15; QVML 1979-3-13).

MAATSUYKER GROUP. De Witt Island (NMV D48802–08, D48902–06, TMH C789–90); Flat Top Island (QVML 1985-3-72); Maatsuyker Island (NMV D37850–54, D37856–57, D37869, D37876, D37884, D37889–96, D37900).

MEWSTONE. (QVML 1985-3-46, 47, 62).

ILE DU GOLFE. (TMH C731–45, C747–70, C772–77).

TASMAN ISLAND. (QVML 1985-3-43).

MARIA ISLAND. Pinnacle, Mt Maria (QVML 1972-3-105); Counsel Creek, 100 m elev. (TMH C311).

THE FRESHWATER INVERTEBRATE FAUNA OF THE LAKE MESTON AREA

by A. M. M. Richardson and R. Swain

(with three tables, four text-figures and an appendix)

RICHARDSON, A.M.M. & SWAIN, R., 1989 (31:x): The freshwater invertebrates of the Lake Meston area. *Pap. Proc. R. Soc. Tasm.* 123: 275–286. ISSN 0080–4703. Department of Zoology, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001.

Collections of littoral invertebrates were made from 21 freshwater bodies in the Lake Meston area of the western Central Plateau. Seventy-three taxa, including 42 identified as species, were collected. The fauna is similar to that found in other high-altitude lakes in Tasmania. A cluster analysis of sites by the presence or absence of species classified the standing waters into groups which could be explained by size and their species richness, apart from Lake Bill, probably the only lake of non-glacial origin, which did not associate with lakes of similar size. No correlations could be detected between the groupings and topographic descriptors of the lakes derived from maps. The named lakes in order of species richness were Meston (29 species), Adelaide & Louisa (23), Poa (19), Myrtle (15), Bill (11) and Charles (7). Lake Meston is apparently the only lake in the area to support a substantial trout population.

Key Words: Central Plateau, Tasmania, invertebrates, lakes, streams, cluster analysis.

INTRODUCTION

Although Tasmania has a wealth of highland lakes there have been few studies of their invertebrate fauna, and those lakes that have been investigated have been the larger or more accessible systems. Perhaps because of the difficulty of obtaining consistent samples in the littoral zones of lakes (Leonard & Timms 1974), the littoral fauna has been less studied than the benthos. Leonard & Timms (1974) described the littoral rock fauna of Lakes Dove, Sorell and Crescent and suggested that the trophically poorer lakes were dominated by insects whereas the richer lakes were dominated by non-insects. Knott *et al.* (1978) examined the rock fauna in Hartz Lake, found that it was dominated by crustaceans, and suggested that this was related to the absence of trout from this lake, in contrast to those examined by Leonard & Timms. The only other substantial studies of the invertebrates of Tasmanian lakes have been the benthic surveys of Timms (1978) and Fulton (1983a,b).

In February 1986 a survey of lakes in the north-western part of the Central Plateau was organised by the Inland Fisheries Commission to investigate the potential of the unstocked lakes as trout fisheries. This provided the opportunity to sample and describe the invertebrate fauna of these lakes, and some neighbouring systems.

The survey included five of the larger and deeper lakes of this part of the Plateau: Lakes Meston, Adelaide, Louisa, Myrtle and Bill (fig. 1). The four largest lakes, Meston, Adelaide, Louisa and Myrtle, all appear to be of glacial origin (Derbyshire 1972, Derbyshire *et al.* 1965), while Lake Bill is not in a rock basin (Derbyshire *et al.* 1965) and may have arisen from the damming and subsequent redirection of Jacksons Creek, which drains Lake Myrtle into the Mersey River. The area also has a large number of smaller lakes and tarns.

Jurassic dolerite outcrops throughout the area, with accumulations of till in some valleys (Mines Department 1976). The vegetation varies with altitude and drainage; extensive stands of *Nothofagus* forest surround Lake Louisa and many of the other lakes, but most of the area is covered with open eucalypt forest on the thinner soils, or swamp and sedgeland where the drainage is poor. The higher ground of Mt Rogoona used to carry alpine dwarf forest, but this has been largely destroyed by recent fires.

Lake Meston was stocked with rainbow trout in the 1940's and the lake apparently maintains a substantial population of trout. The status of the other lakes is unclear. Lake Adelaide may once have been stocked, but no trout were found. The other three lakes do not appear to have trout populations at this time (French 1984).

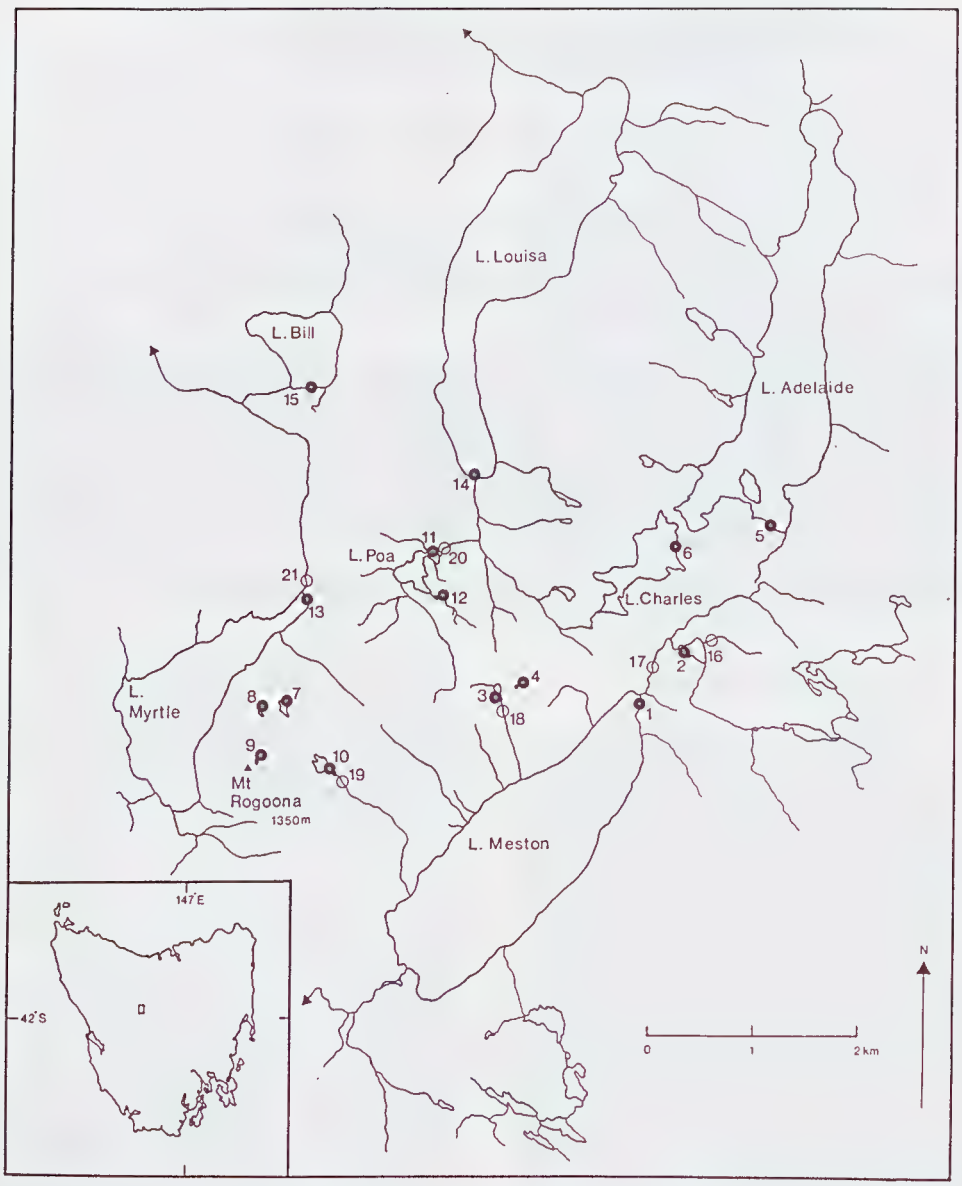

FIG. 1 — Outline map of the Lake Meston area, showing the major water bodies, streams and sampling localities (open circles represent collecting stations in streams, closed circles those in lakes, tarns and pools).

No other published information is available on the limnology or biology of these lakes, though bathymetric surveys of Lakes Meston and Adelaide have been carried out (P.A. Tyler, pers. comm.).

METHODS

In February 1986, the five major lakes, plus a number of smaller lakes, tarns and streams were surveyed from a base camp at the eastern end of Lake Meston.

Collections were made at each locality by hand, i.e. picking animals from the surface of rocks and pieces of wood, and by Freshwater Biological Association hand nets in deeper water along soft banks and in weed beds. At each site collections were made from the full range of littoral habitats available.

At one or two localities burrows of freshwater crayfish were excavated with spades. From Lake Meston and Lake Louisa some material was collected from deeper water by SCUBA diving; tangle nets were used in Lake Meston to collect freshwater crayfish. Finally, flying insects were collected, using a light trap at Lake Meston and by means of hand nets elsewhere .

Apart from Lake Meston, most sites were only sampled on one occasion and no attempt was made to assess the abundance of the species collected.

No physical data were collected from the lakes in the field, but several parameters describing the standing water bodies were estimated from the 1:25 000 map of the area: the area in km^2, the area of the catchment in km^2, altitude (m), length of shoreline (km), maximum length (km), maximum width (km). From these, three more parameters were calculated: the ratio of catchment area to lake area (C/A), the mean width (area/maximum length) and the shoreline development (Bayly & Williams 1973), i.e. the ratio of the shoreline length to the circumference of a circle with the same area, calculated as

$$\frac{S}{2\sqrt{\pi A}}$$

where S = length of shoreline, A = lake area.

RESULTS

Figure 1 shows the locations of the 15 lentic and 6 lotic sites sampled. Other collecting sites, i.e. where crayfish burrows were excavated, are not marked.

Table 1 lists the taxa collected at each site, identified as far as published taxonomies allow. Groups for which the level of identification is particularly poor and where there are likely to have been several species present are the Trichoptera, Chironomidae and Oligochaeta.

In all, 73 taxa were identified, of which 42 were identified to species. The fauna was dominated by insects, especially the nymphs of stoneflies. Amongst the non-insect fauna were molluscs; *Physastra gibbosa* and, less commonly, *Isidorella hainesii*, and the very common small bivalve *Pisidium casertanum*. Oligochaetes and turbellarians occurred at many sites.

Crustaceans were represented by calanoid copepods, ostracods, cladocerans, amphipods, syncarids and decapods. Two species of crangonyctoid amphipod were present, one of which, identified from the keys in Williams & Barnard (1988) as *Neoniphargus alpinus*, was widely distributed in still and running waters, while the other, *N. ?fultoni*, was only found in an alpine pool on Mt Rogoona. The other amphipods were an eusirid, *Paracalliope* sp. (Lake Louisa only), and the ceinid *Austrochiltonia australis*. The syncarid, *Anaspides tasmaniae*, was only found at two sites: a tarn on Mt Rogoona (site 7) and the Lake Meston inflow creek (site 17), where it was very localised. Two species of crayfish were present, *Parastacoides tasmanicus tasmanicus*, which was found in type 2 burrows (Horwitz & Richardson 1986) at several localities, and *Astacopsis franklinii*, which was collected by diving and by tangle nets in Lake Meston, where specimens with a carapace length of more than 100 mm were obtained. One *A. franklinii* female was carrying newly-hatched young.

In order to form a classification of the water bodies studied, the data were subjected to a cluster analysis. Similarities between the sites were measured in terms of the presence and absence of species at each, using Euclidean distance (Clifford & Stephenson 1975, Pielou 1984). The resulting matrix of dissimilarities was converted into clusters of sites using the group average (UPGMA) method (Sokal & Sneath 1973, Clifford & Stephenson 1975) and expressed as a dendrogram. Analyses were performed by the program BIOΣTAT II (Pimentel & Smith 1985)

Since results of cluster analysis can be seriously biased by the presence of rare species, or the failure to collect them at some sites, the analysis was carried out on a reduced data set containing 18 species, selected because they occurred at at least three of the total number of sites examined and

TABLE 1

Invertebrate taxa identified from collections made in Lake Meston area

	Site number*																				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Platyhelminthes																					
Turbellaria	1	1	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Temnocephalida																					
Annelida																					
Oligochaeta	1	1	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1
Hirudinea	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Mollusca																					
Gastropoda																					
Planorbidae																					
Physastra gibbosa	1	1	0	0	1	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
Isidorella hainesii	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Bivalvia																					
Sphaeriidae																					
Pisidium casertanum	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Crustacea																					
Copepoda																					
Calanoida	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cladocera	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Malacostraca																					
Syncarida																					
Anaspides tasmaniae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Amphipoda																					
Crangonyctoidea																					
Neonipharguś alpinus	1	0	1	1	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0
N. ?fultoni	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ceinidae																					
Austrochiltonia australis	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Eusiridae																					
Paracalliope sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Astacura																					
Parastacidae																					
Astacopsis franklinii																					
Parastacoides t. tasmanicus																					
Arachnida																					
Hydracarina	1	1	0	1	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0
Insecta																					
Ephemeroptera																					
Leptophlebiidae																					
Atalophlebioides sp.	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	1	1
Atalophlebia sp.	1	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0
Atalonella sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Siphlonuridae																					
Tasmanophlebia sp.	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Plecoptera																					
Eustheniidae																					
Eusthenia spectabilis	1	0	1	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0
E. costalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Notonemouridae																					
Austrocerca rieki	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1
A. tasmanica	0	0	1	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0
Austrocercella christinae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrocercoides zwicki	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
A. sp.	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Notonemoura lynchi	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

	Site number*																				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Gripopterygidae																					
Leptoperla varia	1	1	0	0	1	1	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0
L. beroe	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0
Cardioperla varia																					
C. incerta	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C. sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinotoperla serricauda	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Riekoperla sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neboissoperla sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata: Anisoptera																					
Aeschnidae																					
Austroaeschna hardyi	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Synthemidae																					
Synthemis tasmanica	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zygoptera																					
Lestidae																					
Austrolestes io	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
A. annulosus/psyche	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
A. cingulatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera																					
Corixidae																					
Sigara sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S. sp. 2	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Notonectidae																					
Anisops sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anisops ?	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae																					
Naucoris congrex	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Coleoptera																					
Psephenidae																					
Sclerocyphon lacustris	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S. secretus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Helodidae	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Helminthidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dytiscidae	0	1	0	1	1	0	1	1	1	1	1	1	0	1	0	1	0	1	0	0	0
Gyrinidae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera																					
Chironomidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1
Simuliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Trichoptera																					
Hydrobiosidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hydroptilidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Polycentropidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Limnephilidae	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0
Kokiriidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tasimiidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Hydropsychidae	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Calocidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicophidae	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atriplectidae	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Calamoceratidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Philoreithridae	1	1	1	0	1	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1
Leptoceridae	0	1	1	1	1	0	1	1	1	0	1	1	0	0	1	0	0	1	0	0	1
Odontoceridae	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Helicopsychidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* The 21 collecting sites are shown in figure 1.

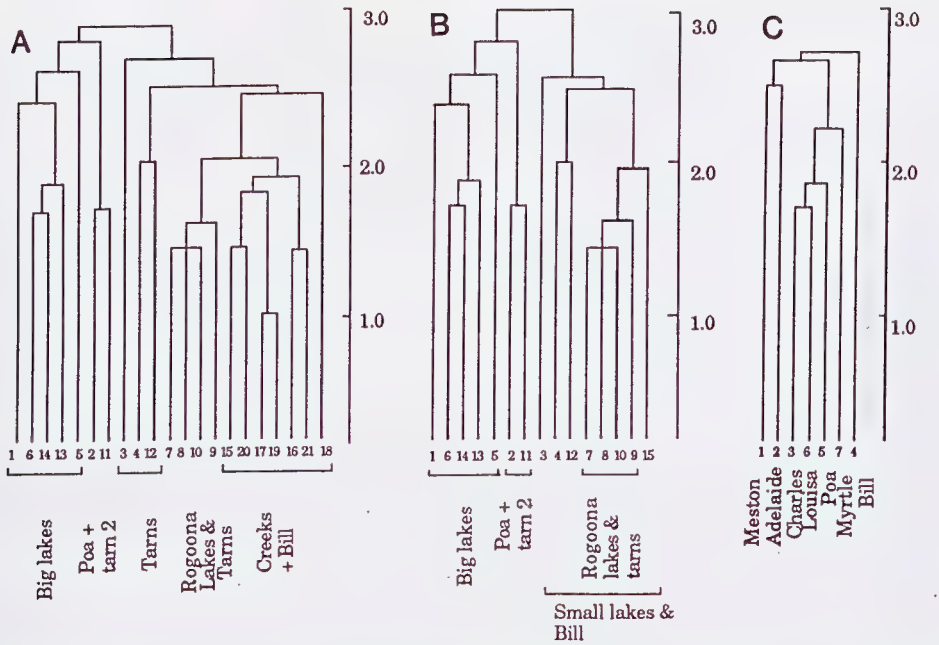

FIG. 2 — Dendrograms resulting from cluster analyses of the collecting stations by species (dissimilarity measure: Euclidean distance, clustering strategy: UPGMA). (a) all sites, (b) lentic sites only, (c) large lakes only. Site numbers refer to the localities in figure 1, apart from dendrogram (c) where the numbers refer to lakes as follows. 1, Lake Meston; 2, Lake Adelaide; 3, Lake Charles; 4, Lake Bill; 5, Lake Poa; 6, Lake Louisa; 7, Lake Myrtle. The vertical scale is dissimilarity measured as Euclidean distance.

could be identified to at least generic level. The occurrences of all species and the selected species set are presented in the appendix. Three groups of sites were analysed separately: the complete set (21 sites), the lentic sites alone (15 sites) and the named lakes alone (7 sites). The resulting dendrograms are shown in figure 2.

Analysis of all sites (fig. 2A) shows a basic division of the sites into the large lakes, plus Lake Poa and Site 2, against the smaller lakes and tarns, plus all the lotic sites. Lake Bill is included in the second group. This division is based partly on species richness, the second group of sites having lower numbers of species, but there is also one absolute difference in the fauna: the presence of the snail *Physastra gibbosa* at all the sites in the first group and none in the second. No other absolute differences appear, but the stonefly *Leptoperla varia* is present at all the sites in the first group but only two out of the 14 in the second group.

Within the second group, subdivisions also correlate with species richness. The Rogoona lakes and tarns are depauperate and have little that characterises them, apart from the absence of species and the presence of *Austrocerca tasmanica*, which they share with only Site 3 and Lake Bill. The creeks and Lake Bill form an indistinct group.

When the lotic sites are excluded from the analysis (fig. 2B), the pattern remains similar to that in the previous analysis. The initial division is into the larger lakes versus the tarns and Lake Bill, and is based on species number and the presence of *Physastra gibbosa*, *Leptoperla varia*, *Atalophlebia* sp. and *Eusthenia spectabilis*, and the absence of *Austrocerca tasmanica* and *Sigara* sp. 2, in the lakes. Within the "big" lake group, Lake Poa and Site 2 are separated from the bigger lakes by the presence of *Tasmanophlebia* sp., *Austrocercoides* sp., *Austrolestes io*, and the absence of *Eusthenia spectabilis*.

In the "small" lake group the only recognisable subgroup is the Rogoona lakes, characterised, as mentioned above, only by their species poorness.

The final analysis is of the named (i.e. "big") lakes only (fig. 2C). Not surprisingly, in view of the relationships described above, Lake Bill separates from all other lakes. This is based principally on the absence of species (e.g. *Physastra*

gibbosa, which was present in all the other lakes), but also on the presence of *Austrocerca tasmanica*. The other principal division is between Lakes Meston and Adelaide and the remaining lakes. These two large lakes have the most species recorded and share *Austrocercoides zwicki* to the exclusion of all the others. *Austrocerca rieki* is only found in Meston, Adelaide and Myrtle within this group.

Summarising the significant points from this analysis, there appear to be at least three groupings within the standing waters samples, which correlate basically with size: the mountain tarns (c. <2 ha.), which are species poor but possess *Austrocerca tasmanica*, the medium-sized lakes (Lake Poa, Sites 2 & 3), which are intermediate in species richness and not characterised by the exclusive possession of any species, and the large lakes (Meston, Adelaide, Myrtle, Louisa, Charles), which are richest in species and best characterised by *Physastra gibbosa*, *Leptoperla varia* and *Eusthenia spectabilis*. Lake Bill does not fit with any of these groups, except the mountain tarns.

To provide some environmental basis for the classification, the lentic water bodies were subjected to a cluster analysis on the basis of the topographic parameters taken from the 1:25 000 map (table 2). Each parameter was transformed to its z-value to prevent the numerically large items from dominating the rest (Clifford & Stephenson 1975). The resulting dendrograms are presented in figure 3.

The analysis is apparently most strongly influenced by the catchment/area ratio, since lakes 2 and 3, with the two highest C/A's, split off early from the rest. Within the remaining group the four largest lakes group together, as do the smallest (sites 4, 8, 9 & 12). These groupings, although they can be related quite easily to the topography of the lakes and their catchments, do not bear any close resemblance to the groupings based on the fauna.

The named lakes can be ranked on the basis of species richness. In order of declining richness, the ranking is: Meston (29), Adelaide & Louisa (23 each), Poa (19), Myrtle (15), Bill (11) and Charles (7). Once again, Lake Meston stands out but,

TABLE 2

Topographical characteristics of the lentic water bodies of the Lake Meston area, derived from the 1:25 000 map

Site No.	Area (A) km²	Catchment (C) km²	C/A	Altitude m	Shore length km	Shoreline development*	Max length km	Mean width km	Max width km
1	2.07	16.4	6.1	1018	19.8	3.4	3.4	0.79	1.1
2	0.03	3.82	119.4	1040	1.7	2.7	0.3	0.11	0.25
3	0.005	0.17	34.2	1100	0.3	1.2	0.15	0.03	0.05
4	0.003	0.005	1.7	1160	0.2	1.0	0.03	0.10	0.03
5	2.34	8.7	3.7	1055	24.8	4.6	4.1	0.57	0.88
6	0.28	0.86	3.1	1060	9.6	5.2	1.1	0.25	0.50
7	0.006	0.12	19.5	1250	0.8	2.9	0.18	0.03	0.05
8	0.001	0.002	2.0	1340	0.1	1.0	0.01	0.10	0.01
9	0.001	0.002	2.0	1340	0.1	1.0	0.01	0.10	0.01
10	0.022	0.26	11.8	1260	1.6	3.0	0.28	0.08	0.13
11	0.079	1.84	23.3	1030	3.6	3.6	0.5	0.16	0.25
12	0.001	0.002	2.0	1030	0.1	1.0	0.01	0.10	0.01
13	1.25	4.9	4.0	1207	16.3	4.1	2.4	0.52	0.88
14	2.29	24.1	10.5	847	23.7	4.4	4.0	0.57	1.0
15	0.44	2.9	6.8	951	6.7	2.9	1.0	0.43	0.75

* as defined in text (p.277)

compared to the cluster analysis, Lake Poa changes its position relative to Lakes Myrtle and Bill.

Table 3 shows correlations between species richness in each of the standing water bodies and the topographic parameters. There are significant relationships between species richness and six of the nine parameters (area, catchment area, shoreline length, maximum length, mean width and maximum width); however, all of these correlate strongly with lake area. Figure 4 shows that there is a weak relationship between species richness and lake area; the greatest deviations from the relationship are for Lake Charles (lower species richness than expected), Lake Meston and "Meston 1" tarn (higher species richness than expected). Including further topographic variables in a multiple regression improves the strength of the relationship dramatically, but further analysis is probably not helpful because of the strong relationships between most of the topographical parameters and lake size; those parameters which are not strongly correlated with lake size (catchment/area, shoreline development and altitude) do not correlate significantly with species richness. While supporting the general relationship between lake area and species richness, this analysis does not explain the exceptional position of Lake Bill in all the cluster analyses.

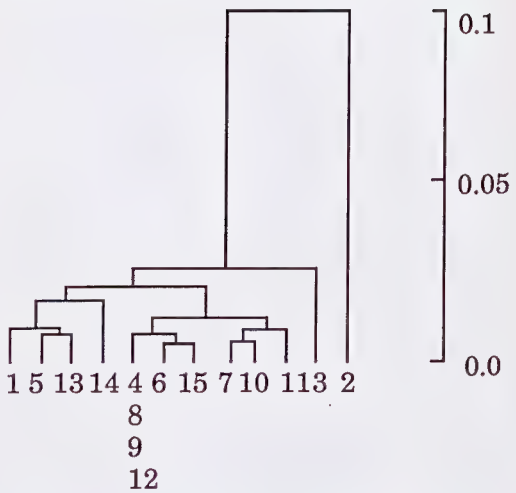

FIG. 3 — Dendrogram resulting from cluster analyses of the lentic collecting stations by topographical parameters (dissimilarity measure: Euclidean distance, clustering strategy: UPGMA), based on nine parameters (lake area, catchment area, C/A, altitude, perimeter length, shoreline development, maximum length, mean width, maximum width). The site numbers refer to the localities in figure 1. The vertical scale is dissimilarity measured as Euclidean distance.

TABLE 3

Correlation coefficients (Pearson's product moment coefficient) between species number in all standing water bodies and the physical parameters derived from the topographic map (table 2).*

	Spp. no.	Area	Catchment area	C/A	Altitude	Shore length	Shoreline development	Max. length	Mean width	Max. width
Spp. No.	1.000	0.739	0.767	0.265	-0.585	0.683	0.465	0.724	0.688	0.670
Area	0.73	1.000	0.881	-0.227	-0.498	0.978	0.617	0.993	0.921	0.900
Catch. area	0.767	0.881	1.000	-0.044	-0.626	0.836	0.508	0.867	0.804	0.803
C/A	0.265	-0.227	-0.044	1.000	-0.171	-0.230	-0.028	-0.210	-0.261	-0.160
Altitude	-0.585	-0.498	-0.626	-0.171	1.000	-0.524	-0.464	-0.527	-0.521	-0.595
Shore length	0.683	0.978	0.836	-0.230	-0.524	1.000	0.748	0.995	0.924	0.935
Shore dev.	0.465	0.617	0.508	-0.028	-0.464	0.748	1.000	0.700	0.618	0.742
Max. length	0.724	0.993	0.867	-0.210	-0.527	0.995	0.700	1.000	0.921	0.923
Mean width	0.688	0.921	0.804	-0.261	-0.521	0.924	0.618	0.921	1.000	0.973
Max. width	0.670	0.900	0.803	-0.160	-0.595	0.935	0.742	0.923	0.973	1.000

* Critical value for coefficient at 0.01 level of probability = 0.641.

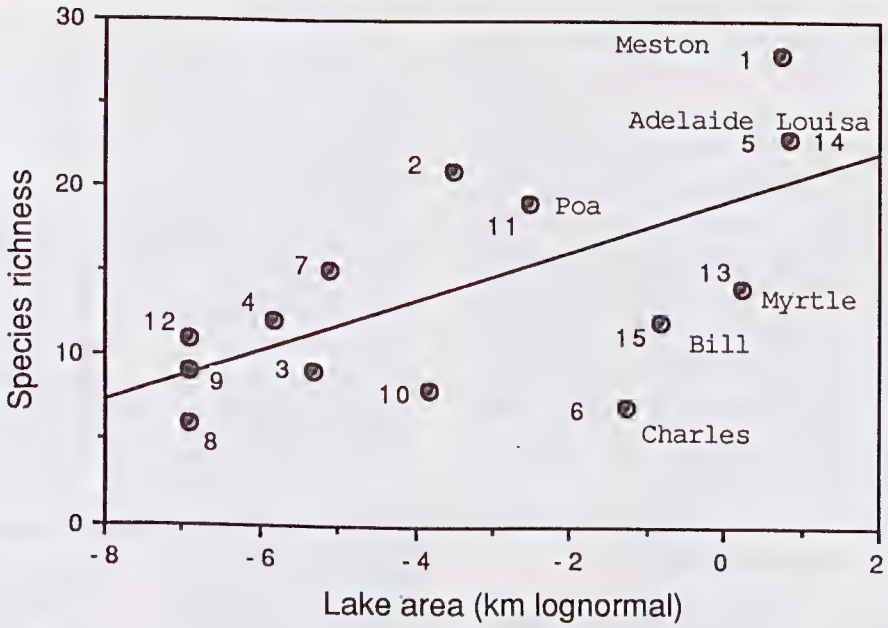

FIG. 4 — The relationship between the number of species collected in the lentic habitats and the area of the water bodies. The numbers refer to the localities in figure 1. The line gives the least squares regression ($Y = 19.036 + 1.481X$; $r^2 = 0.428$).

DISCUSSION

Low levels of identification make it hard to compare the fauna in the Meston lakes and those previously examined, i.e. Dove Lake, Lakes Sorell and Crescent (Leonard & Timms 1974) and Hartz Lake (Knott *et al.* 1978). Not surprisingly, the littoral fauna of the Meston lakes appears to relate more closely to that of Dove and Hartz Lakes than the lower altitude lakes of Sorell and Crescent. The latter lakes have a better developed molluscan fauna, more turbellarians and their crustacean fauna includes representatives of two groups not found in the highland lakes: the janirid isopods (*Heterias petrensis*) and the atyid shrimps (*Paratya australiensis*). *Anaspides tasmaniae* is absent from the lowland lakes, but present in the Meston area, and Hartz Lake.

Within the Meston area, it is clear that Lake Meston stands apart from the other lakes both in terms of species richness and in the occurrence of unique taxa (the gripopterygid stoneflies *Dinotoperla serricauda* and *Riekoperla* sp. and the caddisfly familes Kokiriidae and Helicopsychidae). It is interesting that this lake carries a thriving trout population, while the others support very low or no populations at present. The success of the trout in Lake Meston may be related to the invertebrate faunal richness. There is apparently nothing in the physical size or setting of Lake Meston which might explain the difference. Other factors which might be important, but about which there is no information, are the overall level of productivity, the quality of the surrounding catchments and the exposure of the lakes to wind and wave action.

Leonard & Timms (1974) point out the high variability between samples from the littoral zone in lakes and suggest a number of factors which contribute to this variability. In this study the factor most likely to cause bias in our comparisons is the position of collecting stations in the lakes. Most lakes were sampled at only one general locality (although several samples were collected in that area to allow for local variation) because of the size of the lakes and the restricted access. Because of the configuration of the lakes, Meston and Myrtle were sampled on shores exposed to the prevailing wind, while relatively sheltered shores

were sampled at Lakes Adelaide and Louisa.

A general relationship between lake area and species richness is to be expected from ecological theory (Macarthur & Wilson 1967), but the area available to the littoral fauna is not related to lake area in a simple way, and other factors such as catchment quality, substrate type and productivity will control the number of species present. Lake Bill, which has an exceptional fauna, appears to have had a different origin to the other large lakes. Lakes Meston, Adelaide, Myrtle and Louisa appear to be glacial features, and Poa and Charles are probably kettle lakes with rocky bottoms and shores; but Lake Bill is shallow with an organic bottom and peaty shores (Derbyshire *et al.* 1965), apparently formed from the damming of a small creek. The differences in substrate, and probably in water quality, are sufficient to explain the exceptional fauna in Lake Bill.

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REFERENCES

Bayly, I.A.E & Williams, W.D., 1973: *INLAND WATERS AND THEIR ECOLOGY*. Longman, Melbourne.

Clifford, H.T. & Stephenson, W., 1975: *AN INTRODUCTION TO NUMERICAL CLASSIFICATION*. Academic Press, New York.

Derbyshire, E., 1972: Pleistocene glaciation of Tasmania: a review and speculations. *Austr. Geogr. Stud.* 10: 79–94.

Derbyshire, E., Banks, M.R., Davies, J.L. & Jennings, J.N., 1965: *A GLACIAL MAP OF TASMANIA. Roy. Soc. Tasm. Spec. Publ.* 2.

French, G., 1984: *TASMANIAN TROUTING, WHERE AND HOW*. Greg French, Orford, Tasmania.

Fulton, W., 1983a: Macrobenthic fauna of Great Lake, Arthurs Lake and Lake Sorell, Tasmania. *Aust. J. Mar. Freshwater Res.* 34: 775–785.

Fulton, W., 1983b: Qualitative and quantitative variation in the macrobenthic fauna of the orginal and new lake areas of Great Lake and Arthurs Lake, Tasmania. *Aust. J. Mar. Freshw. Res.* 34: 787-803.

Horwitz, P.H.J. & Richardson, A.M.M., 1986: An ecological classification of the burrows of Australian freshwater crayfish. *Aust. J. Mar. Freshw. Res.* 37: 237–242.

Knott, B., Suter, P.J. & Richardson, A.M.M., 1978: A preliminary observation on the littoral rock fauna of Hartz Lake and Hartz Creek, southern Tasmania, with notes on the water chemistry of some neighbouring lakes. *Aust. J. Mar. Freshw. Res.* 29: 703–715.

Leonard, B.V. & Timms, B.V., 1974: The littoral rock fauna of three highland lakes in Tasmania. *Pap. Proc. R. Soc. Tasm.* 108: 151–156.

Macarthur, R.H. & Wilson, E.O., 1967: *THE THEORY OF ISLAND BIOGEOGRAPHY*. Princeton University Press, Princeton, N.J.

Mines Department of Tasmania, 1976: *GEOLOGY OF TASMANIA, 1:500 000 MAP*. Tasmanian Department of Mines, Hobart.

Pielou, E.C., 1984: *THE INTERPRETATION OF ECOLOGICAL DATA*. John Wiley, New York.

Pimentel, R.A. & Smith, J.D., 1985: *BIOΣTAT*. Sigma Soft, Placentia, California.

Sokal, R.R. & Sneath, P.H.A., 1963: *PRINCIPLES OF NUMERICAL TAXONOMY*. W.H. Freeman, San Francisco.

Timms, B.V., 1978: The benthos of seven lakes in Tasmania. *Arch. Hydrobiol.* 84: 422–444.

Williams, W.D. & Barnard, J.L., 1988: The taxonomy of crangonyctoid Amphipoda (Crustacea) from Australian freshwaters: foundation studies. *Rec. Aus. Mus., Suppl.* 10:1–180.

(accepted 10 February 1989)

APPENDIX 1

Occurrences of all recognised taxa in the 21 sites examined in the Lake Meston area

	MEST	L2	L3	T4	ADEL	CHAR	T7	T8	T9	L10	P0A	T12	MYRT	L14	BILL	C16	C17	C18	C19	C20	C21
Turbellaria	1	1	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Oligochaeta	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
Hirudinea	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
*Physastra gibbosa**	1	1	0	0	1	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
Isidorella hainesii	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
*Pisidium casertanum**	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Calanoida	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cladocera	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Anaspides tasmaniae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
*Neoniphargus alpinus**	1	0	1	1	1	0	0	0	1	0	0	1	1	1	0	0	0	1	0	0	0
N. ?fultoni	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
*Austrochiltonia australis**	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Paracalliope sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Hydracarina	1	1	0	1	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0
Atalophlebioides sp.*	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	1	1
Atalophlebia sp.*	1	0	0	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0
Atalonella sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Tasmanophlebia sp.*	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
*Eusthenia spectabilis**	1	0	1	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0
E. costalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
*Austrocerca rieki**	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1
*A. tasmanica**	0	0	1	0	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0
Austrocercella christinae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*Austrocercoides zwicki**	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
A. sp.*	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0
*Notonemoura lynchi**	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
*Leptoperla varia**	1	1	0	0	1	1	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0
*L. beroe**	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0
Cardioperla incertae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C. sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinotoperla serricauda	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Riekoperla sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neboissoperla sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austroaeschna hardyi	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Synthemis tasmanica	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Autrolestes io	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
*A. annulosus**	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
A. cingulatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sigara sp.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S. sp.2*	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0

continued

	MEST	L2	L3	T4	ADEL	CHAR	T7	T8	T9	L10	P0A	T12	MYRT	L14	BILL	C16	C17	C18	C19	C20	C21
Anisops sp1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. sp.2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoris congrex	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Sclerocyphon lacustris	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S. secretus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Helodidae	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Helminthidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dystiscidae	0	1	0	1	1	0	1	1	1	1	1	1	0	1	0	1	0	1	0	0	0
Gyrinidae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1
Simulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hydrobiosidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hydroptilidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Polycentropidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Limnephilidae	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0
Kokiriidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tasimiidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Hydropsychidae	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Calocidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicophidae	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atriplectidae	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Calamoceratidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Philoreithridae	1	1	1	0	1	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1
Leptoceridae	0	1	1	1	1	0	1	1	1	0	1	1	0	0	1	0	0	1	0	0	1
Odontoceridae	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Helicopsychidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Taxa constituting the selected data set.

ERRATUM: LAND USE ON CAPE BARREN ISLAND, TASMANIA

by R. A. Perrin

PERRIN, R.A., 1989 (31:x): Erratum: Land use on Cape Barren Island, Tasmania. *Pap. Proc. R. Soc. Tasm.* 123: 287. ISSN 0080–4703. PO Box 763, Rockhampton, Queensland, Australia 4700.

An error occurs in figure 4, p.77, of the paper by Perrin (122(2), 1988) on Cape Barren Island. In this figure areas underlain by granite are shown as limestone, those underlain by limestone are shown as granite.

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